

Optimization of Risk Management by Life Cycle Costing and Application to the European Train Control System

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Alexander Jankowski

from Braunschweig, Germany

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Professoral advisor Prof. Jörn Pachl

Prof. Renzo Ciuffi

Prof. Georgia Giovannetti

Prof. Joachim Stahlmann

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Abstract

The main objective of this PhD thesis entitled “Optimization of Risk Management by Life Cycle Costing and Application to the European Train Control System” is to optimize allocation of limited resources for risk management by means of Whole Life Cycle Costing. According to the task, the main subject is the relationship between safety risk management and WLCC. The formulated problem is “to generate a model to evaluate the costs for safety technology versus costs for emergency management from the viewpoint of WLCC”. [Prof. Pachl]

For this purpose, safety risk management, financial risk management and Whole Life Cycle Costing (WLCC) are combined and refined into a new concept called Holistic Life Cycle Optimization (HLCO). On this basis, a new Universal HLCO Approach is developed that permits flexible and individualized optimization of any investment. One of its important components is the Model Choosing Approach, which systematizes, by means of appropriate selection criteria, selection of the most suitable models for HLCO analysis. The Universal HLCO Approach is the perfect tool for evaluating the costs for safety technology versus costs for emergency management from the viewpoint of both safety risk management and WLCC. If desired, it not only optimizes all costs, but also simultaneously all benefits, uncertainties, risks, chances and their dependences of any investment object.

Furthermore, to justify higher investments in measures of risk management, a new explanatory model called Marketing Substitution is suggested for quantification and prognosis of damages due to subjective risk perception of events of damage. It is applied to safety, security, availability, i.e., to the value of human life and health, environment, cultural heritage, malicious human behaviour such as terrorism, etc., and late arrivals.

Additionally, new statistic/stochastic models called Mean Risk and Mean Chance are developed as improved measures of mean negative or positive deviations instead of traditional ones such as absolute deviation, variance, standard deviation, or lower partial moment, etc.. On this basis, new improved selection decision models called Relative Reinvestment Profitability and Absolute Reinvestment Profit are developed to summarize any frequency/probability distribution. Selection decision models help to choose the best alternative from the set of available ones. To consider simultaneously all dependences between all random variables a new aggregation model called Aggregation to Net Terminal Value with Dependence Factors is developed to overcome the weaknesses of correlation and regression analyses. By means of the Net Terminal Value, it can calculate the Real Profit/Profitability.

Furthermore, a new computer-aided design decision model called the Simultaneous Design Decision Algorithm is developed to achieve the main objective of the dissertation. It simultaneously optimizes the investment mix, the financial risk reserves, and the credit amount in an accelerated way. Additionally, it can find the optimal replacement alternative and moment if replacement investments are elements in the set of available alternatives. The elements in the set of available alternatives are, among other things, also investments in measures of risk management. Thus, the optimal mix represents the optimal allocation of limited resources for both risk management and WLCC.

Finally, the new concepts and models are demonstrated on railway systems, especially by applying them to the European Train Control System (ETCS). In this context, a new economical and safety-relevant technical principle is developed for onboard verification of train integrity. Altogether, the new theoretical research results are universal and applicable to all investments in practice. Thanks to the synergetic effects in this case, the newly developed or improved methodology has enormous potential.

List of abbreviations, acronyms, and symbols

Abbreviation	Unit	Description
A		(Investment) alternative
$A_{CH,m}$		Average at mean chance referred to the mean m
$A_{R,m}$		Average at mean risk referred to the mean m
AIRR	%	Adjusted internal rate of return
ARP		Absolute Reinvestment Profit
a – upper index		Aggregated considering dependences by correlation coefficients or dependence factors
B	€	Benefits: $B = B^- + B^+$
B^+	€	Positive benefits
B^-	€	Negative benefits, future costs
B_{cr}	€	Credit, outside capital
$B_{cr \max}$	€	Maximally allowed credit amount
C	€	Costs: $C = I + B^-$
C_D	€	Costs due to damages
C_F	€	Costs of operational function without the cost share of damages ($C_{Io} + C_o$)
C_{Io}	€	Costs of investments in operational functions without safety functions
C_{Is}	€	Costs of investments in safety functions (i.e., cost share for integrated safety)
C_o	€	Costs for the operation of the investment object without damages
C_{total}	€	Total costs, WLCC
CA		Subjective chance attraction
CH	€/a	Chance(s)
D		Damage, event of damage
DLCC		Differential Life Cycle Costing
DPB	a	Discounted payback
d		Average deviation
E		Stochastic expected value
ERTMS		European Rail Traffic Management System
ETCS		European Train Control System
EVC		European Vital Computer
e.g.		Exempli gratia (= for instance)
etc.		Et cetera
F		fractal
f		Function
f_s		Subjective evaluation functions
G	€	Profit
GSM - R		Euro - Radio standard
g		Geometric mean
HLCO		Holistic Life Cycle Optimization
HMI		Human Machine Interface
I	€	Initial costs
I_e	€	Equity capital
IRR	%	Internal rate of return
ΔI	€	Chosen cost step

Δi_j	€	Minimally possible cost step for alternative A_j
i	%	Constant interest rate
i_t	%	temporarily variable interest rate
i.e.		Id est (= that is to say)
L		Likelihood (probability or frequency)
LC		Likelihoods of Causes of events of damage
LCC		Life Cycle Cost(-ing)
LCP		Life Cycle Profit calculation principle
LD		Likelihood of damage amount
LE		Likelihood of events of damage
LEU		Lineside Electronic Unit
LPM		Lower partial moment
MARR	%	Minimum Attractive Rate of Return
MG		Minimal subjective goal ($P_{MG} = 1 + MARR$)
MMI		Man Machine Interface
m		Mean (statistic arithmetic mean or stochastic expected value)
$m_{CH,m}$		Mean (deviation) chance referred to the mean m
$m_{R,m}$		Mean (deviation) risk referred to the mean m
max		maximize
min		minimize
N		Limited number of iterative improvements to avoid endless processing time
NB		Net benefits
NPV	€	Net present value
NS	€	Net savings
NTV	€	Net terminal value
N.N.		nomen nescio (= the name of the author is unknown)
n		Total number of years
OLAP		On - Line Analytical Processing
P		(Annualized) profitability
P_{total}		Total profitability
p		probability
pl		Planning period
Q		Quantile
R	€/a	Risk(s)
RA		Subjective risk aversion
RAMSS		Reliability, Availability, Maintainability, Safety, Security
RBC		Radio Block Centre
ROI	%	Return on investment
RRP		Relative Reinvestment Profitability
r		Linear correlation coefficient
S	m	Distance
$S_{beginning}$		Driven distance by the locomotive
S_{end}		Driven distance by the last goods wagon
SDDA		Simultaneous Design Decision Algorithm
SF	€	Sinking funds
SIR		Savings to investment ratio
SPB	€	Simple payback
STM		Specific Transmission Module
s		Skewness
ΔS	m	Difference between the beginning and the end of a train

$\Delta S_{\text{coupling}}$	m	Difference between the beginning and the end of a train per coupling
T_{lim}		Time limit for processing time
TACC	€	Total annual capital charge
TD		Write off damage
t	a	Calculatory period in time, year t
UPM		Upper partial moment
VaR		Value at Risk
var		Variance
WLCB		Whole Life Cycle Benefit(-ing)
WLC		Whole Life Cost(-ing)
WLCC		Whole Life Cycle Cost(-ing)
Z	€	Allowed deviations to avoid endless processing time
σ		Standard deviation

1 Introduction

1.1 Objectives of the dissertation

Natural catastrophes and manmade disasters are perpetual dangers. Many lives have been lost to and enormous material and ecological damage incurred as a result of them. Additionally, the potential damages in modern and sophisticated societies are increasing rapidly due to growing population density and the dramatically increasing complexity of new technologies. Furthermore, increasing cost pressures demand maximal use of all potential technical and organizational means of risk management. Therefore, a lot of resources are expended on risk management in order to minimize the negative consequences of such incidents.

This dissertation is promoted by the German Research Society (DFG) within the framework of the European Graduate College IGC 802 "Risk Management on the Built Environment, Pre-Warning and Monitoring of Natural and Man-Induced Disasters as Prevention / Reduction Measures"¹. As inherently stated in the name, the main objective of this graduate college is general improvement of risk management for buildings and infrastructures with regard to an optimal allocation and use of limited resources. The built environment is especially endangered through risks derived from natural and anthropogenic disasters. Due to the similar methods of risk research both the natural catastrophes and the human-caused disasters are in the focus of the graduate college. [Plate 2000].

The main objective of this PhD thesis with the title "Optimization of Risk Management by Life Cycle Costing and Application to the European Train Control System" is to optimize allocation of limited resources for risk management by means of Whole Life Cycle Costing.

For that purpose, safety risk management, financial risk management and investment management, especially Whole Life Cycle Costing (WLCC) will be combined to form a new concept called Holistic Life Cycle Optimization (HLCO). The new research results will be demonstrated using railway systems as examples, especially by applying these results to the European Train Control System (ETCS).

As a rule, the consequences of railway accidents are not as dramatic as those of natural catastrophes. However, accidents involving technical systems are also capable of causing enormous damage and pose a high risk to society. [1] Railways are one of the safest means of transportation. Nevertheless, accidents happen occasionally. However, railway accidents often attract enormous public attention and media interest despite, or perhaps precisely because of, the fact that they are infrequent and usually result in tremendous damage. [2] Therefore, the aspects of objective risk acceptance and subjective risk perception will be considered in this context, too. In particular, a new explanatory model for quantifying damages due to subjective risk perception will be developed in this PhD thesis. Thanks to the synergetic effects in this case, these research results hold enormous potential. Attainment of the stated objectives will be of considerable benefit to society. [1]

1.2 Tasks of the dissertation

The author applied within the Graduate College for project field A, project A1.

¹German title: „Risikomanagement bei Natur- und Zivilisationsgefahren für Bauwerke und Infrastrukturanlagen“

“Project Field A: Fundamentals, Methods, Strategies

Project A deals with the principles, methods and strategies of risk analysis, risk assessment and risk management, which will then be used in all the sub-projects. One of the objectives of this project is to develop the principles of the methods and strategies employed by the different users. Numerical and algorithmic aspects will be considered [...] to develop methods and strategies for life cycle assessment of structures.” [1]

“Project A1: Questions of Solving Stochastic Problems

One class of stochastic problems deals with the stochastic occurrence of hazards in components of complex safety systems. In order to analyse the context of diverse risk factors of individual system components relating to safety of the entire system special methods [...] can be used. [...] All methods [...] for solving stochastic problems lead to an enhancement in performance during design and during operation. They also avoid losses in economical and human sphere.” [1]

Professor Pachl formulated the tasks and problems of the dissertation as follows:

“The main subject of the PhD thesis should be the relation between safety and LCC. In contrast to other subjects in the field of safety assessment, in which a lot of research is already being done, e.g., into problems such as risk and hazard analysis, safety and LCC is a very new topic that allows to produce new and valuable results on a very fundamental level. The objective is to generate a model to evaluate the costs for safety technology versus costs for emergency management from the viewpoint of LCC. The basic problem of safety and LCC can be found in all infrastructures that require expensive effort for safety technology and emergency precautions, such as tunnels, large buildings, high-voltage installations, etc.. Finally, the developed model and new results could be demonstrated using the German (or other international) railways as an example, (e.g., by evaluating the consequences of railway disasters).” [Prof. Pachl]

1.3 Structure and contents of the dissertation

Following this initial introductory Chapter 1 (see Fig. 1.1), Chapters 2 and 3 describe the current relevant fundamentals of risk management and Whole Life Cycle Costing respectively. They provide information about the current state of the art in safety and WLCC research. In Chapter 4, risk management and Whole Life Cycle Costing are integrated with one another and refined into a new concept called Holistic Life Cycle Optimization (HLCO).

Afterwards, Chapter 5 presents the relevant fundamentals of descriptive models. This chapter deals especially with (standard) breakdown structures, which are the most important descriptive models in HLCO. Chapter 6 describes the relevant fundamentals of explanatory models and introduces a new explanatory model that serves to quantify and predict damages due to subjective risk perception of events of damage.

Chapter 7 presents the relevant fundamentals of prognostic, statistic/stochastic, and aggregation models. In particular, it introduces new statistic/stochastic models for quantification of mean negative and positive deviations as measures of mean risks and chances. Afterwards, these are applied in the new aggregation model, which considers all dependences by means of

new so-called “Dependence Factors”. Chapter 8 uses the new results from Chapter 7 for new selection and design decision models.

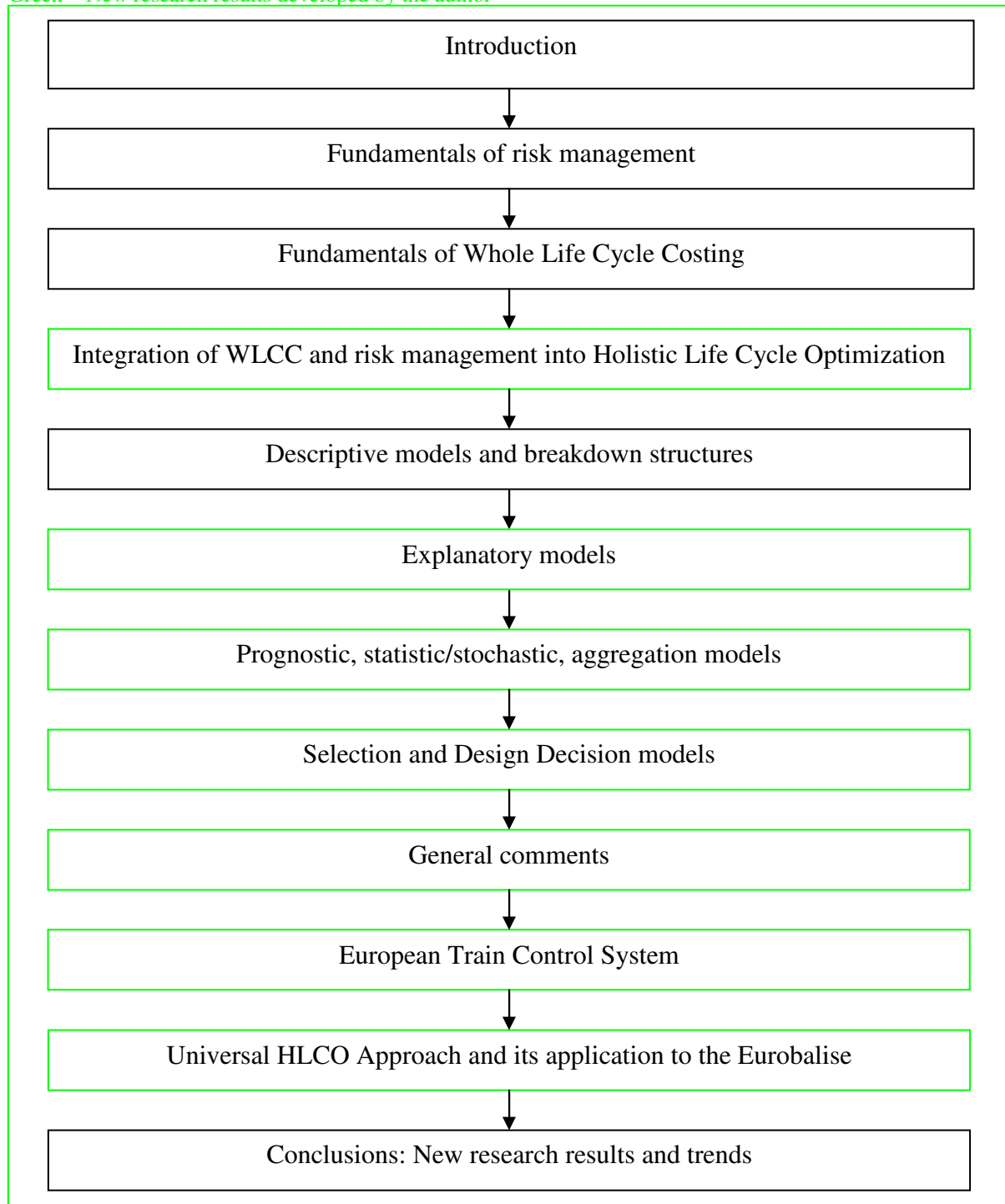
Chapter 9 contains general comments regarding many frequently asked questions and potential problems in the context of risk management and WLCC. The author explains these and suggests some new or improved solutions.

Chapter 10 describes the relevant fundamentals of the European Train Control System (ETCS). The ETCS serves as a practical example that is also interesting for international risk management because of its international character and pertinence to safety. In this context, the author introduces a new economical, technical solution, pertinent to safety, for checking train integrity aboard freight trains. Chapter 11 presents the new Universal HLCO Approach and applies it to railway systems, concretely to the Eurobalises.

Chapter 12 recapitulates all of the essential new ideas and research results in the dissertation as conclusions. Moreover, it offers a look ahead towards future developments and research trends in this scientific field.

Fig. 1.1: Contents and structure of the dissertation

Green = New research results developed by the author



2 Risk management

This chapter describes the relevant fundamentals of risk management in order to offer an overview of the current state of knowledge in the scientific field of risk research.

2.1 Definition of terms in risk management

In order to describe risk management, it is first necessary to define the term *risk* and other similar terms and learn to differentiate between them.

2.1.1 Damage

Any explanation of the term *risk* first requires an understanding of the term *damage*. *Damages* are material or ideal disadvantages incurring due to an event of damage. The German Civil Code defines *damage* as the difference between the assets before and after an event of damage. The time value of damaged assets must be considered, too. This means that when quantifying damages, one must consider that older and used assets may have a different value than new ones do. When it comes to insurance, *damage* is the central term of damage insurance and results from the negative influence on the insured interest. [3]

Within the meaning of safety science, *damage* is a harmful influence on the rights of a person due to the physical-chemical impact resulting from use of a technology. Damage is measured in terms of human lives, persons injured, monetary values or other suitable units. [2, 4]

2.1.2 Risk, Damage risk

“The word *risk* derives from the early Italian word ‘risicare’, which means ‘to dare’. In this sense, risk is a choice rather than a fate.” [5, 6] “*Risk as a general noun* is defined as exposure to the chance of injury or loss; a hazard or dangerous chance” [5, 7]

In business management theory, *risk* means venture. *Ventures* are dangers of losses that lie in the nature of business. They are namely all hazards, uncertainties and random factors that accompany all business activities. They frequently result from general or industry-specific disturbances in the market.

In insurance management theory, *risks* are insurable if the insurer can calculate the premium whose benefits are equivalent to the deterioration resulting from the transferred risks. The insurability is especially limited for cumulated and extremely high risks. However, the insurability of risks can be improved by means of reinsurance.

In statistical decision theory, *risk* describes the degree of uncertainty. In the case of risk, one knows objective probabilities for future events. [8] Risk is, by definition, the expected value/the mean of a damage distribution. However, it is crucial to understand that “...risk is not just bad things happening, but also good things not happening...” [5] In both cases, we deal with damages or losses. “Thus, various definitions of risk imply that we expose ourselves to risk by choice, and that is an important point: Risk arises from choice.” [5]

In safety science, *risk* is, by definition, the product of damage and its *likelihood* (stochastic probability or statistical frequency). [1, 5] This definition of the term risk serves as the basis for the graduate college and this dissertation.

$$\text{risk [€/a]} = \text{damage} * \text{likelihood of damage} = \text{detrimental deviation} * \text{likelihood}$$

The same definition is used for all types of risks: damage risks, financial risks, etc.. The likelihood of events of damage is measured either according to time (e.g., events of damage per year) or, as is usual in transportation, according to output (e.g., events of damage per million person kilometres). Accordingly, the *dimension of risk* is either Euro per year or Euro per million person kilometres.

Technical risks can be subdivided into the three following categories:

- Unproblematic, routine risks (household, job, traffic, leisure time, etc.),
- Problematic risks (chemical industry, hazardous good transportation, long tunnels, etc.),
- Critical / politicized risks (nuclear energy, genetic engineering, etc.). [2, 9]

From a linguistic point of view, the meaning of the term *risk* is similar to that of the terms *venture* or *hazard*. In economics, this may mean both the possibility of economic loss and the opportunity to make a profit. In order to avoid confusion, within the meaning of safety science, we will use the term *damage risk* as a substitute for the term *risk in the economic sense*. *Damage risk* describes the “venture that disadvantageous effects of all kinds can occur, but do not necessarily really occur.” [2, 4]

2.1.3 Chances

When discussing risk as a dangerous detrimental/negative chance, it is necessary to define its opposite in this context, namely the term beneficial/positive *chance*.

Chance is a French word meaning a favourable opportunity to achieve something, the possibility of success. [10] In most economic literature, chances are included in risks. Some authors, however, distinguish between chances and risks. In this thesis, the author also explicitly distinguishes between the two terms because it is advantageous, especially in the sense of risk management. The formula for chances is very similar to the one for risks.

$$\text{chance [€/a]} = \text{beneficial deviation} * \text{likelihood}$$

Chances are the opposite of risks, the “other side of the coin”. *Deviation risks* are the summed up products of detrimental deviations from the reference value multiplied by the corresponding likelihoods of these detrimental deviations. Thus *deviation chances* are the summed up products of beneficial deviations from the reference value multiplied by the corresponding likelihoods of these beneficial deviations.

In summary, both risks and chances are measured as products of negative or positive consequences respectively deviations and their corresponding likelihoods, where likelihood represents stochastic probability or statistic frequency. Consequently, both risks and chances are of probabilistic nature. [5]

2.1.4 Insecurity and uncertainty

Insecurity is the generic term for the terms risk and uncertainty [11] which are frequently used synonymously, despite the fact that risks deal with objectively measurable probabilities, whereas in cases of uncertainty these are impossible to assign. This means that in cases of *risk* a definable probability distribution is known. In contrast to risk, one speaks of *uncertainty* if

objectively measurable probabilities cannot be defined for outcomes of the random variable. [12] Nevertheless, it is possible to assign subjectively estimated probabilities for uncertainties.

“*Uncertainty* as a general noun is defined as ‘the state of being uncertain; doubt; hesitancy’. [...] It is simply what is not known with certainty, but not the unknown.” [5, 7] “Uncertainty exists in all situations that are unknown, unpredictable, open ended, or complex, but matters that are unknown or unpredictable are too difficult for analysis. Uncertainty can be best described as a subset of unpredictability, which in turn is a subset of the unknown. The reason is that an uncertain matter is not unknown or unpredictable. We simply lack information and knowledge about it; we lack certainty.” [5]

Consequently, our present level of knowledge determines the *degree of uncertainty*, i.e., whether a matter is unknown, unpredictable, uncertain or risky. The degree of uncertainty can vary significantly. For example, in the same type of events of damage we know a lot about frequent events with low damages and very little about seldom events with extreme damages. Additionally, different decision makers possess different information and processing capacities. Thus, for the first decision maker, frequent storms with low damages could constitute a risk and seldom storms with extreme damages an uncertainty. For a second decision maker, on the other hand, all storms may be uncertainties because he has no information about storms and no processing capacities or limited cognition to forecast such complex processes. [5]

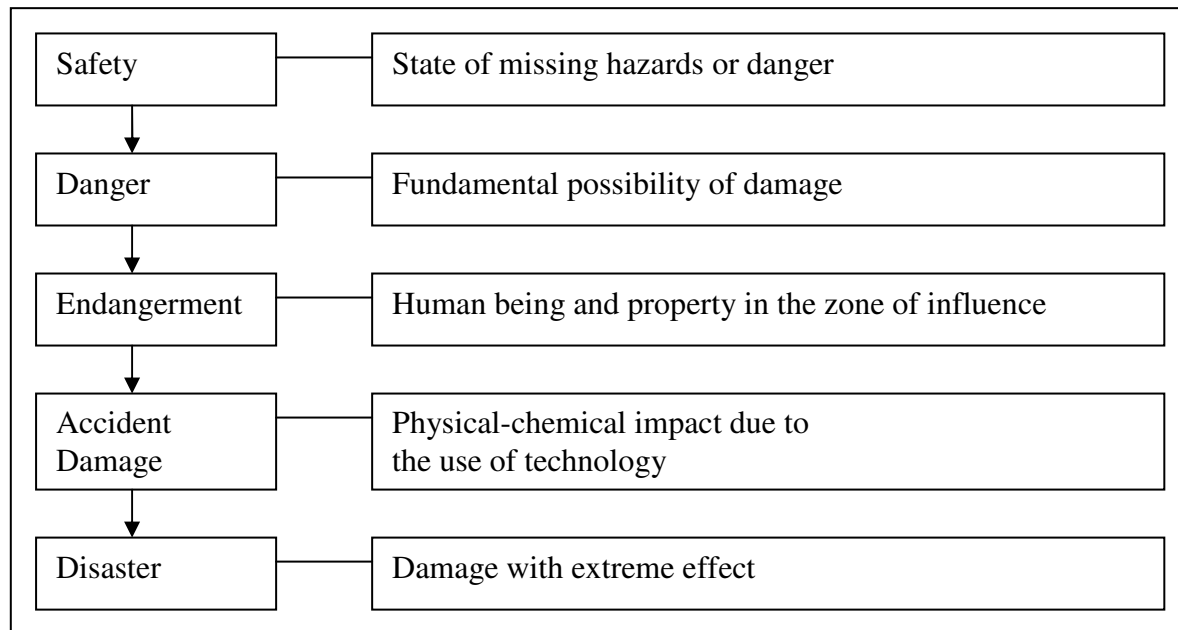
2.1.5 Technical hazard and danger versus safety

In decision theory, *safety* describes the degree of uncertainty for which only one single future outcome is expected. In the field of transportation, *safety* is the feature of a transportation system to transport objects without any damages. Additionally, the aspects of reliability, availability and even maintainability are also crucial because delays can also cause damages. [13]

A *danger* can mean the general/fundamental possibility of personal injury or property damage when using a technical system. However, an *endangerment* exists when a human being or a property is actually in the zone of influence of a technical system. Both terms, *danger* and *endangerment*, contain the possibility, but not the certainty of damage. Otherwise, the term *safety* includes the certainty that possible damages will not occur, or in general language usage the state of lack of danger [2, 14].

Fricke and Pierick [15] define *safety* in general usage “...objectively as a state of missing danger.” or “...subjectively as a state, in which one is protected against possible dangers.” [2, 15]. Further: “... Since human life consists of very different activities (staying at home, job, traffic, leisure time), [...] the term *safety* must be understood relatively. For example, *traffic safety* does not describe the absolute absence of danger, but a specific ratio for the occurrence of safe states related to the set of all states (safe and not safe)” [2, 16]. Furthermore both [15] contradict the opinion “... that often understands the *total risk* as the reciprocal value of the safety ...; ... if we want to take safety as the reciprocal value for the risk, we must add to the total probability of the harmful events the total probability of the dangerous events as unsafe states that did not cause a damage by coincidence, but certainly could”. [15]

The two terms safety and endangerment are presented in the German standard DIN 40 041 [17] as follows: *Safety* is defined as the attribute of an object, not to cause any danger under default conditions during a specific period of time or not to let danger arise. There is an *endangerment* if a system state is not controllable anymore with the given means and can cause personal injury. Further definitions are presented in Fig. 2.1 in accordance with DIN. [2]

Fig. 2.1: States between safety and disaster due to the use of technology [17]

2.1.6 Incidents and accidents

Kuhlmann [4] subdivides accident-like damage events into four groups with different ranges and importance. However, accident-like damage events are “...suddenly occurring and temporary limited.” [4]. An *incident* corresponds to a *disrupted operation* in a technical system. The incident is defined as a breakdown, on the condition that a case of danger is excluded right from the start. The *case of danger* includes the danger of personal injury or property damage while an *accident* represents an event in which personal injury or property damage always occurs. A technical system where danger comes from is a *danger source*. If this is locally definable, a *danger field* can be determined. *Endangering potential* characterizes the amounts of possible damages caused by a technical system. One can distinguish between *normal* and *disrupted operations*. The upper boundary of the endangering potential of a technical system is designated as a *danger potential*.

Perrow [18] distinguishes accidents and breakdowns for systems. The systems are divided into four levels of varying complexity (parts, units, subsystems and systems): “*Breakdowns* concern damage to or failure of parts or units, *accidents* concern damage to or failure of subsystems or of the total system” [18]. The systems can be distinguished with regard to their linkage (closely/slack) and their complexity (linear/complex). For example, Perrow [18] interprets rail transportation as a linear and closely coupled system.

A delimitation of hazard and danger states as well as accidents can be carried out by means of the features: cause, duration period, collision partners and intervention options [2, 19]. Accordingly, there is a *danger state* when, after an erroneous action, a collision partner does not exist yet and the hazard can be eliminated by a correcting intervention. On the other hand, an *endangering state* is spoken of, if a collision partner exists and the safe system state can no longer be achieved by any correcting intervention, but only by rescue operations. Finally, in an *accident*, the endangering state changes into a state with effective damage.

A similar opinion speaks of the *absence of endangerment* if there is not any unfavourable state. [2, 20] If an unfavourable state arises, the state of the *latent endangerment* is achieved.

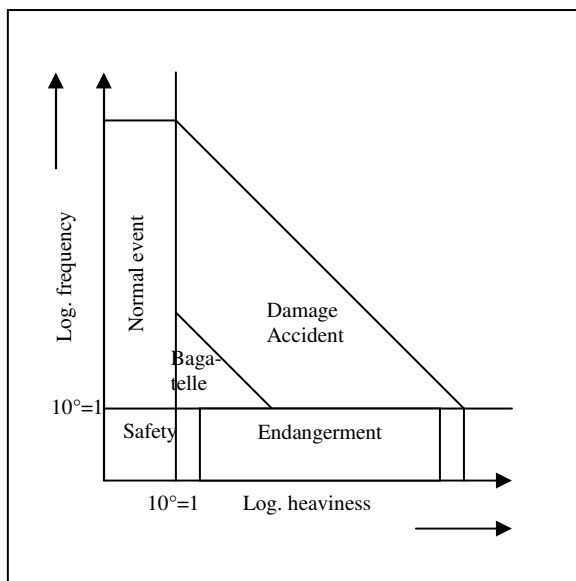
In this case, protective intervention is still possible. Otherwise, the state of *acute endangerment* follows. If rescue operations are no longer possible, the *damage state* occurs. [2]

2.1.7 Disaster

Accidents or damages with extreme effects are designated as *disasters* or synonymously as *catastrophes*. A better definition according to Compes [21] states that: “Disaster is a damage event in a societal/environmental system, occurring and progressing in a limited period of time and of such manner and severity that, because of its consequences, the demand for life support noticeably exceeds the capacity of the system. Therefore, components or functions of the system are cancelled or destroyed and extreme to total losses arise”. [21] (See Fig. 2.2).

Low frequency with low severity remains within the framework of *bagatelle cases*, outside of this range, *damages* and *accidents* are defined; with increasing severity, damage grows until the beginning of a *disaster*. On the other hand, according to Compes [21] there is also a disaster if the frequency achieves the level of an epidemic. That means either very many units are damaged with low severity or few units with very high severity. He classifies disasters emanating from the fields of environment, society and technique. The chronological aspect is important in this context, too, for instance if a disaster is sudden and abrupt (e.g., aircraft crash) or latent and crawling (e.g., drought in Sahel). [2]

Fig. 2.2: Qualitative and quantitative event classification according to Compes [21]



“A *disaster* occurs only if an extreme event strikes a vulnerable population. [...] A disaster is a state, in which a population, a population group, or an individual is not able to cope, i.e., is not able to overcome the adverse effects of the extreme event, without the help from outside. Impact and magnitude of a disaster are determined by human influences. From these definitions, the social dimension of vulnerability becomes apparent.” [22] Furthermore, disasters with the same financial damages can lead to different social consequences for the various affected parties.

We speak of a *disaster* if *vulnerability*, i.e., the degree of affection by an extreme event, exceeds *resistance*, i.e., the ability independently to regenerate or to repair the damage. The future values of resistance and vulnerability should also be taken into account.

Consequently, there exist three methods of disaster mitigation:

- Reducing vulnerability
- Increasing resistance
- Reducing damages and/or their probabilities of occurrence

Reducing vulnerability and increasing resistance are long-term objectives, which require politically supported socio-economic measures. Reducing damages and/or their probabilities of occurrence is a faster solution. [22]

In this thesis, all disasters, accidents, incidents and bagatelles are called *events of damage*. Thus an event of damage could be a natural disaster, a man-induced accident, a breakdown of production or even a contractual delay (e.g., late arrival of a train).

2.1.8 Management and international management

To explain the term *risk management* it is not enough only to understand what is meant by *risk*; one also has to understand the term *management*. *Management* is not defined homogeneously in the literature. However, an institutional point of view and a functional one are usually distinguished.

In the institutional point of view all persons of an enterprise that perform a management function are assigned to the management. The following classification considers the organizational hierarchy:

- Top management
- Middle management
- Lower management

In the functional point of view, all tasks and activities necessary for leading an enterprise, that are not solely of operational nature, are designated as management. That means that important specifications concerning objectives, strategies, methods and means are to be made. Management signifies making and interspersing decisions about the use and allocation of own resources (capital and property, personnel, information), and considering competing alternatives and restrictions by planning, leading and controlling. Functional management simply means making decisions (within a defined context, for example in an enterprise). [23]

We speak of *international management* if international transactions are the object of management activities. This definition includes practically every kind of activity abroad. However, activities abroad that are of such low importance for the entire enterprise that they are not the object of the management at all are excluded. [24]

2.1.9 Risk management

Risk management generally means the management of all risks, chances and uncertainties. *Risk management as a management function* understands risks as dangers that accompany the process of formulating and reaching objectives. Risks can influence this process in a negative way. However, risks are always associated with all activities. Risks that are not identified and confronted in time can endanger the successful development of the investor and even put it in a crisis in the sense of critical processes for survival. Risk management in the narrow sense deals with insurable risks. In a general definition risk management considers all relevant risks. Thus, risk management can be seen as either special risk management or as general risk management.

The object of *special risk management* is protection against so called pure risks that are interpreted as insurable risks. This view of risk management is still dominant in practice and has very high importance because of continuously increasing services offered by insurers. Special risk management evidences a process character and is subdivided in single phases oriented according to the general management process:

1. Search for and identification of (insurable) risks and analysis of such risks.
2. Search for alternative means of risk reduction. The residual risks must be accepted and self-insured if there are no alternatives for the given concrete situation.
3. Assessment and optimization of alternatives found, usually by comparing costs and benefits.
4. Decision about taking out insurance policies (or self-insurance)
5. Damage control

The instruments of special risk management (insurance management) may include: [25]

1. Risk prevention, i.e., eliminating the sources of risk and/or reducing the probabilities of events of damage.
2. Impact mitigation, i.e., to reduce damages. [5]
3. Self-insurance, i.e., acceptance as residual risk. It is important to observe continuously such residual risks, because if environmental and internal factors change, the risk profile changes as well.
4. External insurance policy, i.e., risk transfer to third parties such as insurers.
5. Involving of captive-insurance-companies, which are insurance companies owned by the investor group itself.
6. Limiting risks contractually.

Special risk management as an institution defines who is responsible for risk management activities. The risk manager and the corresponding divisions occupy the highest positions in the hierarchy of risk management. The risk manager should belong to top management because of his high level of responsibility and interdivisional tasks as well as his coordination function within the whole enterprise.

General risk management means risk conscious management and serves for the preservation and the successful development of the investor by making clear and communicating the risk phenomena for all processes. It is especially important for such typical management activities as the planning and the control.

The *risk conscious culture and philosophy* are even more important. They determine the desired risk level as well as the aspired and practiced risk behaviour. They contain decision criteria and influence the planning. Risk conscious planning is the central field of action of general risk management. Risk conscious planning also determines all subsequent management and control activities. For the management activity “control”, realisation of a general risk management means intensified usage of course controls and especially of so called “proactive controls”.

In the context of financial and result politics the general risk management means conservative financial planning and, as far as possible, consequent reserve planning. Risk conscious result planning can identify risks for results and liquidity by means of periodic result planning and the budgeting. Conservative financial planning, in particular, means maintaining sufficient liquidity reserves, a “healthy” ratio between equity capital and outside capital, secured credit plans and financial business as well as effective debtor management. Additionally, conservative financial planning forbids, for example, operating production facilities through leasing

constructions. [25] True mastery of risk management means not only managing identified risks but also preparing for unidentified risks. [5]

2.2 Objectives and tasks of risk management

The most important economic objective of risk management is protection of sustainable development. *Sustainable development* is defined as following: “First development must not damage or destroy the basic life support system of our planet Earth: the air, the water, and the soil, and the biological systems. Second, development must be economically sustainable to provide a continuous flow of goods and services derived from the Earth’s natural resources, and thirdly, it requires sustainable social systems, at international, national, local, and family levels, to ensure the equitable distribution of the benefits of the goods and services produced, and of sustainable life support systems.” [22, Bruce 1992] Sustainable development may be endangered by disasters.

Consequently, the main tasks of risk management are to develop and to apply comprehensive models and approaches based on risk management for describing, quantifying and forecasting resistance and vulnerability and finding optimal selection or design decisions concerning a fair and logical investment of limited resources to guarantee the sustainable development. [22]

2.3 Importance of risk management

Speaking about the importance of risk management, one should bear in mind that humankind will always be confronted with risks. The only thing that is certain in this world is the fact that nothing is absolutely sure and consequently nothing is absolutely safe. Therefore, one must always manage risks as well as possible in order to reduce their negative effects, insure sustainable development, and be competitive.

Since resources for managing risks (capital and property, personnel, information, knowledge etc.) are always limited, it is necessary to optimize their allocation and use. That means optimizing ratios between benefits and costs, chances and risks of the whole risk management. This is extremely important in the risk management.

All in all, the risk management should be able to manage risks flexibly both in the short term and in the long term. Speaking of the long term, the highest level in the risk management is the ability to deal with still unknown risks.

2.4 Potential problems in risk management

One should view problems in risk management as challenges that are to be confronted and mastered through improved methods.

First challenge: Since managing risks requires reliable forecasting of future risks (concretely of the damages and their probabilities), it is necessary to improve our forecasting methods and databases. The question “How does one deal with new technologies?” is especially interesting in this context.

Second challenge: The limited reliability of prognoses and the relatively high costs of complicated risk analyses together with low communication in this field often causes low acceptance

of risk management and doubt in its methods and benefits. This sometimes leads to low investment.

Third challenge: Low risk communication often results in missing risk awareness and insufficient international cooperation. In this case, wise policy is required.

Fourth challenge: Since we try to optimize the costs and benefits of limited resources, two important questions in risk management are: What residual risk is objectively acceptable for the system operator and society as a whole? Furthermore, what residual risk is subjectively acceptable for individual system customers and consequently for the system operator and society? Hence, our resources and subjective risk perception change over time; we have to ask and to answer these two questions repeatedly from time to time.

2.5 Research trends and research needs in risk management

Since risk management is very important for our society, intensive research will always be required in this scientific field. The following main research trends currently dominate risk management:

The first research trend combines risk management with Whole Life Cycle Costing in order to optimize all costs and benefits of limited resources, considering all risks and chances associated with every alternative. This dissertation concentrates on this issue and deals with it in Chapter 4.

The second research trend attempts to answer questions about objective risk acceptance and subjective risk perception. Especially the question: “How does one quantify, in monetary terms, the negative effects of subjective risk perception?” will be addressed in Chapter 6. Answering these questions is important for better decision-making and therefore should be integrated into WLCC.

The third research trend concerns collecting data and improving forecasting methods. The forecasting methods and required data will be mentioned in Chapters 5 and 6, too.

The fourth research trend is the internationalization of risk management. In the globalized world, we share many risks with our neighbours. Thus, it is simply logical to cooperate with each one another in this field.

The fifth research trend is relatively new. It is the result of events such as the terrorist attack on the Twin Towers in New York. Terrorism is now considered as an additional risk factor in risk management calculations. In this context many difficult questions arise that will also be addressed in Chapter 6.

3 Whole Life Cycle Costing

This chapter describes the relevant fundamentals of Whole Life Cycle Costing in order to provide an overview of the current state of knowledge in this scientific field. In order to explain the term Whole Life Cycle Costing it is necessary to define first the terms costs, life cycle, life cycle costing and explain the meaning of the word “whole” in this context.

3.1 Costs

Costs are monetized quantities of manufacturing resources and third-party services as well as public taxes or charges that are consumed or occupied in order to produce operational goods. [26] *Costs* are monetarily valuated consumptions of economic goods or resources. The economic goods can be of material and immaterial kind. The economical resources are used for manufacturing and sales of material products and immaterial services as well for the creation and the maintenance of required operational capacities.

For the monetary evaluation of consumption we can use either market prices or express the monetary value indirectly through lost benefits (e.g., *opportunity costs*). The lost benefits are used especially then, if the market prices are unknown or external effects incur.

Costs are usually derived from the expenses. [27] That is perhaps the reason why these two terms are often used incorrectly or interchangeably. “*Cost* is a measure of resource consumption related to the demand for jobs to be done, whereas *expense* is a measure of spending that relates to the capacity provided to do a job.” [5] However, in practice it is mostly the resource consumption perspective that counts, since decision makers must match capacity to demand and not vice versa. [5]

3.2 Life cycle

The term *life cycle* represents a concept that assumes that the timely development of an object can be subdivided in characteristic phases. That means we assume that every object has a limited life. We can distinguish between different kinds of life cycle depending on the type of the object.

In the *product life cycle* we assume that the demand for a product goes through different saturation phases from its development until its disappearance from the market. The same product can have different “ages” in different international markets. Also the current phase of the same product can vary from market to market.

In the *industry life cycle* we assume that also a whole industry, as a sum of all its product life cycles, evolves through different maturity phases before its life cycle ends. Of course, all humans have also limited *stakeholder life cycles*. Accordingly, the age or the life phase of stakeholders (e.g., consumers, workers, and shareholders) influences their decision behaviour regarding long-term investments.

The *investment life cycle* is the life cycle of an investment object. An investment object could be for example a single product. Thus, we treat the *life cycle of a single product* like his biography and subdivide it in different phases. In the literature, many different life cycle models are described to subdivide the life cycle of a single product in its different phases. Such mod-

els for single products are always holistic. They describe the “life” of the analysed single product more or less completely from its “birth” until its “death”. For example, the life cycle of a single technical product can be subdivided in following phases:

1. Market research and technical research for the product
2. Development and innovation
3. Manufacturing of the product
4. Marketing and sales
5. Operational usage or consumption in accordance with the originally planned application, and eventually maintenance
6. Operational usage or consumption different from the originally planned application, and eventually maintenance
7. Different ways of disposal or recycling

Usually, just few objects follow really the idealistic life cycle course. Besides, it is mostly very difficult to distinct the exact position of an object in the life cycle. [28] In the context of WLCC, all given above life cycle definitions are relevant. However, the investment life cycle and especially the life cycle of a single product dominate the WLCC.

3.3 Life Cycle Costing

The standard IEC 300-2 [29] defines the term *Life Cycle Costs (LCC)* as cumulated costs of an investment object over its entire life cycle. That means LCC are all costs of an investment object from the first initiating idea until the recycling. LCC include not only the cost of the technical system but also the cost of the total supporting equipment as well as the costs of the necessary infrastructure and labour services required to operate the system. [30, 31]

The term LCC is often used as a synonym for *Life Cycle Costing* and all sorts of Life Cycle Calculations. [30] *Life Cycle Costing* is defined as a “Process of an economic analysis to assess the life cycle cost of an investment object over its entire life cycle or a part of this.” [32]

3.4 Whole Life Cycle Costing

In their book, Boussabaine and Kirkham [12] describe the history of Life Cycle Costing and its current refinement into Whole Life Cycle Costing in the late 1990s. They give many definitions used in the literature for the both terms. The following current definition of Whole Life Cycle Costing (WLCC) is also derived by Boussabaine and Kirkham [12] from their literature research:

“*Whole Life Cycle Costing* is a dynamic and ongoing process which enables the stochastic assessment of the performance of constructed facilities from feasibility to disposal. The WLCC assessment process takes into account the characteristics of the constructed facility, reusability, sustainability, maintainability and obsolescence as well as the capital, maintenance, operational, financial, residual and disposal costs. The result of this stochastic assessment forms the basis for a series of economic and non-economic performance indicators relating to the various stakeholders’ interests and objectives throughout the life cycle of a project.” [12] The given above definition of WLCC will be dominant in this doctoral thesis.

The terms *Whole Life Costing (WLC)* and *Whole Life Cycle Costing (WLCC)* are used synonymously in the literature. The new term WLCC was developed to overcome some of the weaknesses of LCC. Currently, WLCC is accepted by many economists dealing with prognoses and optimizations of the long-term costs of investments.

The absence of any nationally or internationally standardized definitions of WLCC leads to a debate about the differences between LCC and WLCC. Therefore, there are many subjective opinions. Some scientists claim that the terms LCC and WLCC are synonymous. Others insist that differences exist. [33] The author agrees with the survey conducted among academics and practitioners by Boussabaine and Kirkham [34] which serves as the basis of the given above definition of WLCC and summarizes the following differences between the both terms.

Most definitions emphasize that LCC only deals with the economic life, i.e., over the specified period of commercial usage, whereas WLCC is concerned with the whole life, i.e., over the entire life span of the investment object.

It was also noted that the fundamental weakness of LCC is insufficient consideration of risks and uncertainties in prognoses so that investors and decision makers cannot really trust the LCC recommendations. WLCC is a new attempt to integrate risk assessment into the decision making process of LCC. Furthermore, WLCC was criticized for not considering eventual deteriorations of system elements and characteristics of the investment object. [12, 34]

3.5 Benefits

Benefits measure in the benefit theory the ability of an economical good to satisfy particular needs of the investor or consumer. [35] *Benefits* describe the subjectively evaluated ability of an economical good to satisfy needs of a market participant. The term benefit means both the ability to satisfy needs as well the degree of satisfaction that arises to the investor thanks to the consumption of the acquired goods. [36]

Profit-oriented investors such as private enterprises are primarily interested in commercial benefits. Welfare-oriented investors such as non-profit organisations generate mainly public benefits. Both types of investors deal mostly with commercial and public benefits simultaneously. Therefore, the differentiation between commercial and public benefits is more of theoretical nature and has quasi no practical relevance.

Since benefits are per definition subjectively evaluated and often many stakeholders are involved in the decision process the author recommends the usage of the benefit matrix like the one shown in the Chapter 11. The decision maker can consider there the monetary benefit functions of all important stakeholders individually for every benefit element. The importance of the stakeholders is weighted in the benefit matrix.

3.6 Whole Life Cycle Benefiting

The author introduces the term *Whole Life Cycle Benefiting (WLCB)* in the interest of a better structuring and understanding of the concepts. WLCB works very similarly to WLCC. The only main difference between the both concepts is that WLCB concentrates on maximizing benefits i.e., the beneficial properties whereas WLCC minimizes costs i.e., cost properties of the investment object. WLCB underlies the *Life Cycle Profit (LCP)* [37] calculation principle whereas WLCC works according to the *Differential Life Cycle Costing (DLCC)* [32] calculation principle.

Both WLCC and WLCB are derived from the economic principle. According to the lexicons “Gabler Wirtschaftslexikon” and “Brockhaus” the *economic principle* describes the optimal economic behaviour. That is either (the *maximum principle*) to maximize the success (e.g., benefits, profit) with given limited resources (e.g., goods, funds etc.) or (the *minimum princi-*

ple) to minimize the investment of resources required for achieving the pre-set beneficial objectives (e.g., a distinct degree of prosperity). The economic principle is independent of the concrete economic system. [38, 39]

3.7 Measures of economic performance

In this chapter the relevant measures of economic performance will be explained and compared with each other to bring out their differences, advantages and disadvantages.

For every investment optimization the decision maker needs measures of economic performance that can be optimized, that is, either maximized or minimized. Classic WLCC minimizes all costs of the investment object assuming indirectly all benefits as constant and equal for all investment alternatives. Classic financial risk management minimizes risks and chances of the investment object without any differentiations between the both. Classic safety risk management minimizes only the damage risks of the investment object.

The author recommends the benefits/costs coefficients as measures of economic performance because they can represent in an appropriate way simultaneously all costs, benefits, uncertainties, (damage) risks, chances and their dependences. Such benefits/costs coefficients are for instance profitability, profit, return on investment etc..

3.7.1 Profit

The *profit* G is a very basic and popular economic performance indicator. This absolute measure of economic performance is especially favoured in finance. The lexicons “Gabler Wirtschaftslexikon” and “Brockhaus” define profit as the difference between all benefits B^+ and all costs C . [40, 41]

$$G [\text{€}] = B^+ - C$$

Classic WLCC minimizes all costs C of the investment object assuming indirectly all benefits B^+ as constant and equal for all investment alternatives (e.g., $B^+ = \text{const} = 0 \text{ €}$).

$$\Rightarrow \max G = \max (B^+ - C) = \max (0 - C) = \max (-C)$$

Classic WLCB maximizes all benefits B^+ of the investment object assuming indirectly all costs C as constant and equal for all investment alternatives (e.g., $C = \text{const} = 0 \text{ €}$).

$$\Rightarrow \max G = \max (B^+ - C) = \max (B^+ - 0) = \max (B^+)$$

That means in both WLCC and WLCB we always optimize indirectly the total profit or a part of this. The advantage of the profit is the fact that we always can calculate and maximize it as the whole or as a part. However, the disadvantage is also the fact that its meaningfulness is limited because we can only compare alternatives either with equal benefits B or costs C in a fair way. This assumption is very unrealistic. Otherwise, it is unsure that we choose the best alternative. The following simple examples could demonstrate the disadvantage.

Example 3.1: Choose the best alternative.

Alternative 1: $C_1 = 100 \text{ €}$, $B_1^+ = 200 \text{ €}$
 $G_1 = 200 \text{ €} - 100 \text{ €} = 100 \text{ €}$

Alternative 2: $C_2 = 200 \text{ €}$, $B_2^+ = 350 \text{ €}$
 $G_2 = 350 \text{ €} - 200 \text{ €} = 150 \text{ €}$

Maximizing the profit we would choose the second alternative ($G_2 = 150 \text{ €}$). However, we need the double initial costs for that than for the first one. Thus, we could generate even more profit if it is possible to invest two times in the first alternative ($2 * G_1 = 200 \text{ €}$).

If we maximize only benefits in WLCB we would also choose the second alternative ($B_2^+ = 350 \text{ €}$) ignoring the double initial costs.

If we minimize costs in WLCC we would choose the first alternative ($C_1 = 100 \text{ €}$). However, the choice could also be suboptimal if B_2^+ is much higher like in Example 3.2. We would still invest in the first alternative ignoring the eight times higher profit G_2 .

Example 3.2: Choose the best alternative. max G

Alternative 1: $C_1 = 100 \text{ €}$, $B_1^+ = 200 \text{ €}$
 $G_1 = 200 \text{ €} - 100 \text{ €} = 100 \text{ €}$

Alternative 2: $C_2 = 200 \text{ €}$, $B_2^+ = 1000 \text{ €}$
 $G_2 = 1000 \text{ €} - 200 \text{ €} = 800 \text{ €}$

This weakness is typical for all absolute measures of economic performance. To overcome this disadvantage we need relative measures of economic performance such as profitability or return on investment.

3.7.2 Profitability, return on investment

The *profitability* P is a very basic and popular economic performance indicator, too. This relative measure of economic performance is especially favoured in accounting. The lexicons “Gabler Wirtschaftslexikon” and “Brockhaus” define profitability as the ratio between a measure of success and the invested capital, i.e., between all benefits B and initial costs I . [42, 43]

$$P [-] = B / I$$

The advantage of the profitability is that it is mostly more useful for choosing the best alternative than the profit. In Example 3.1 it would recommend us the alternative 1. $P_1 = 2$ means that every invested Euro in alternative 1 will yield us 2 €.

Example 3.1: Choose the best alternative. max P

Alternative 1: $C_1 = I_1 = 100 \text{ €}$, $B_1^+ = 200 \text{ €}$
 $G_1 = 200 \text{ €} - 100 \text{ €} = 100 \text{ €}$
 $P_1 = 200 \text{ €} / 100 \text{ €} = 2$

$$\begin{aligned}\text{Alternative 3.2: } C_2 &= I_2 = 200 \text{ €}, B_2^+ = 350 \text{ €} \\ G_2 &= 350 \text{ €} - 200 \text{ €} = 150 \text{ €} \\ P_2 &= 350 \text{ €} / 200 \text{ €} = 1.75\end{aligned}$$

Unfortunately, it is often impossible or very difficult to allocate exactly all benefits to analysed investment objects. For instance, it is impossible to allocate the fair part of all benefits to such a smaller subsystem as the Eurobalise (assumption: $B_{\text{Eurobalise}}^+ = 0 \text{ €}$). We could only do it for bigger subsystems such as power plants. Therefore, many prefer to maximize the profit instead of the profitability in spite of its unreliable recommendations leading often to suboptimal choices.

The *return on investment ROI* [44] is like the profitability a very popular relative measure of economic performance. In fact, it is related to the profitability and has a similar information and interpretation. In the literature the return on investment is used more often than the profitability. However, in this thesis we will mainly use the profitability because it is more convenient for the most calculations than the return on investment.

$$\begin{aligned}\text{ROI [\%]} &= (P - 1) * 100 = (B / I - 1) * 100 \\ &= G / I * 100 = (B^+ - C) / I * 100\end{aligned}$$

In the literature [12] the interested reader can find the definitions of other measures of economic performance such as simple payback, discounted payback, net savings, savings to investment ratio, internal rate of return, adjusted internal rate of return, sinking funds, total annual capital charge and several different forms of return and of benefits/costs ratios. These economic performance indicators are not described here because in the opinion of the author they are obviously less meaningful than the profit and the profitability and therefore irrelevant for this dissertation. In the end every decision maker wants to maximize the profit/profitability of his investment object.

3.8 Initial costs and future costs

In Chapter 3.7 we used costs in both formulas for the profit and the profitability. While the difference between initial costs and future costs is unnecessary for calculating the profit, it is extremely important when it comes to calculating profitability.

Initial costs I are all costs incurring at the beginning of the investment, in the current calculatory period (usually a year). They are a part of the total capital available for investments in the current calculatory period.

Future costs B⁻ are all costs incurring after the current calculatory period. For instance, even that part of the acquisition costs that must be paid in the second calculatory period belongs to future costs. This difference is important because calculating the profitability the initial costs are the denominator whereas the future costs are together with positive benefits in the numerator. To emphasize that future costs belong together with positive benefits in the numerator they are synonymously called *negative benefits B⁻* in this thesis.

$$C [\text{€}] = I + B^-$$

$$B [\text{€}] = B^+ - B^-$$

$$G [\text{€}] = B^+ - C = B^+ - I - B^-$$

$$P [-] = B / I = (B^+ - B^-) / I$$

A mistaken allocation of costs to the denominator and the numerator is very dangerous and would always generate wrong profitability coefficients, misleading the decision maker into making suboptimal choices.

4 Holistic Life Cycle Optimization

In this chapter risk management and WLCC will be combined and developed further to a new concept, called Holistic Life Cycle Optimization (HLCO).

4.1 Integration of risk management and WLCC to HLCO

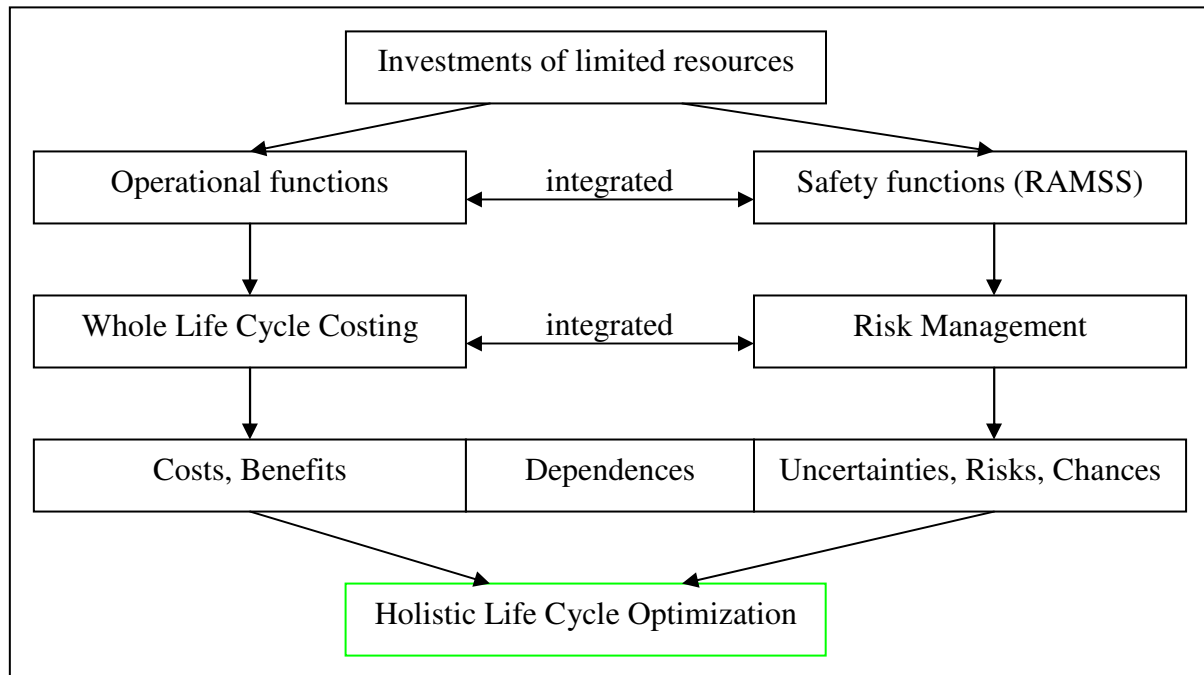
In risk management or in WLCC we always deal with investment decisions. We could see WLCC like a decision model for general investment decisions and their following corrective decisions relating to operational functions. Analogously we can treat risk management like a decision model for investment decisions and their following corrective decisions relating to safety functions.

For investments we require different limited resources such as capital, information, human capital etc.. We can invest them either in setting up operational functions such as driving (e.g., railroads or locomotives) to produce some prosperity increasing goods or in safety functions such as signalling (e.g., ETCS) to protect operational functions against risks.

Investing in operational functions we are more concerned about costs and benefits and try to optimize the benefits/costs ratio. Dealing with pure safety investments we primarily want to optimize the chances/risks ratio. Since in many cases an operational function requires an integrated safety function, it is often even impossible to differentiate exactly between costs for safety functions and ones for operational functions.

The benefits/costs ratio should normally be optimized by means of WLCC and the chances/risks ratio by means of risk management. Since the nature of investments is probabilistic because of risks and uncertainties, perfect WLCC should consider all risks and chances, too. On the other hand, because safety investments should be efficient, all their costs and benefits should also be taken into account. That means theoretically, if we primarily invest in an operational function with an integrated safety function, WLCC is the dominating approach and risk management is just an integrated part of WLCC, but a very important one. Otherwise, if we invest only in a safety function, risk management is the dominating approach and WLCC is just an integrated part of risk management, but also a very important one. (See Fig. 4.1)

An ideal optimization should theoretically include all costs and benefits as well as all uncertainties, risks and chances and all their dependences. That means an ideal optimization should consider all consequences of investments on a long-term basis. Consequently, a perfect optimization approach should be a combination of risk management and WLCC as shown in the Fig. 4.1. Therefore, the author suggests integrating risk management and WLCC into each other in order to improve their efficiency. We call the new resulting concept Holistic Life Cycle Optimization (HLCO).

Fig. 4.1: Integration of risk management and WLCC to HLCO

In HLCO it is unnecessary to differentiate between costs due to safety or operational functions because the total investment object is optimized as the whole with all its functions.

4.2 Definition of Holistic Life Cycle Optimization

Holistic Life Cycle Optimization (HLCO) is a holistic, ongoing and flexible process of investment analysis which enables the stochastic assessment and optimization of the economic performance for every investment object considering the whole life cycles of this and of all its resulting investments beginning in the chosen planning period. HLCO should optimize simultaneously all consequences of ownership due to the initial investment such as all aggregated costs, benefits, uncertainties, risks, chances and their dependences.

The result of the stochastic assessment forms the basis for a series of economic performance indicators relating to the various stakeholders' interests and objectives that can be optimized for the desired planning period considering the whole life cycle of the investment object or a part of this. HLCO is not a one-off calculation. It is ongoing and should be reviewed regularly during the life of the investment object. HLCO could be applied continuously to the total investment program as a universal investment and business strategy.

The attribute “*holistic*” in the context of HLCO means that one should consider holistically all consequences of the investment and its resulting investments beginning in the planning period from the first initiating idea until their disposal. Therefore, the HLCO assessment process takes into account the characteristics of the investment object, reusability, sustainability, maintainability and obsolescence as well as the capital, maintenance, operational, financial, residual and disposal costs. Thus, it includes not only all cost of the technical system but also of the total supporting equipment, of the necessary infrastructure, for labour services required to operate the system, as well as all capital and revenue costs (e.g., taxes etc.). HLCO considers all operational costs of the investment object including energy, utilities and facility management elements that relate to the investment object, such as maintenance and cleaning, security and catering. It also refers to replacing components.

Additionally, it is possible to consider all deviation, financial, safety and security risks in HLCO. Safety risks reflect all potential damages due to accidents and disasters such as train accidents and floods etc.. Security risks represent all potential damages due to malicious human behaviour such as terrorism, vandalism, sabotage, espionage, etc..

The holistic methods are usually the best if they are flexible enough. HLCO is extremely flexible. Nothing in HLCO is absolutely mandatory. It makes only best-practice recommendations that should be followed if they are efficient in the concrete decision situation.

When one considers a life cycle, its wholeness is implied. In HLCO, we should consider not only consequences up to the point when the investment object is no longer economically viable, but also the issues that relate to its disposal. HLCO goes beyond that to include consequences beyond working life. In case of a building project therefore demolition costs, for example, would be included.

4.3 Differences between Risk Management, WLCC and HLCO

The following text summarizes the most important differences between risk management, WLCC and HLCO which explain what is new in HLCO and why an additional concept is required:

- Classical WLCC concentrates mostly on costs and less on benefits. Classical risk management focuses primarily on risks, uncertainties and eventually on dependences but not on chances. In HLCO it is recommended to consider equally all costs, benefits, uncertainties, risks, chances and their dependences.
- Unlike WLCC, HLCO considers explicitly the damage risk management. Therefore, it does not fail like WLCC if the analysed investment object is destroyed in an event of damage before the end of the chosen planning period.
- HLCO is more flexible than WLCC or risk management because it gives only recommendations for the best practice adapted to the concrete decision situation.
- HLCO recommends optimizing if possible the profitability of the total investment program while WLCC optimizes primarily the profit of its subordinate elements.
- If reasonable, HLCO explicitly allows considering more subjectivity in the analysis process than WLCC and risk management do. For example, subjectivity could lead in HLCO to better decisions that are individually adapted to the risk behaviour of the decision maker.
- HLCO favours aggregation to the Net Terminal Value (NTV) instead of the Net Present Value (NPV) in WLCC.
- The planning period can be chosen by the stakeholders in HLCO more flexibly than in (W)LCC. WLCC considers ideally all consequences of the investment object from the beginning until the end of its life cycle. LCC depends on the perspective of the investor and considers only all consequences until the end of economic life. HLCO follows the supply chain and indirectly considers for the investor the whole life cycle of the initial investment and its resulting investments that begin in the planning period.
- HLCO can use more powerful tools developed or improved by the author to overcome the weaknesses of risk management and WLCC.

How can HLCO help to reduce risks?

HLCO improves the usage of limited resources optimizing among other things all risks associated with investments. The saved resources can be used for other investments in operational

or safety functions. HLCO is the perfect tool for selecting or designing the optimal safety investment (program). That means, HLCO increases the decision quality in risk management by helping to answer the following questions:

- How does one optimize the investment object considering its all costs, benefits, uncertainties, risks, chances and their dependences?
- How safe is safe enough?
- How much are we willing to pay for safety?
- How much and how should we invest in safety functions?
- How to determine acceptability limits, the optimal risk level (i.e., residual risk)?
- How to quantify subjective risk perception?
- How to consider (potential) damages on environment, cultural heritage etc.?

Does HLCO fail if the analysed investment object is destroyed in an event of damage before the end of the chosen planning period?

In order to handle the influence of accidents and disasters on the useful life (see Chapter 7.4.2) of the analysed investment object it is necessary to consider that the useful life is not deterministic but probabilistic. That means there is always some risk that the system will fail in the first calculatory period (e.g., year) or in anyone later until the presumed end of the useful life. Nevertheless, there is also the chance that the system will function longer than the expected useful life.

Usually, the chosen (deterministic) economical period of use represents the time until the re-investment and replacement of the system by a newer one. The failure of the system before the end of the planning period, caused by an accident or a disaster or even bad quality or excessive / wrong use etc. should be always considered in HLCO. Only this permits a fair comparison of different investment alternatives because it makes the associated (damage) risks transparent.

In HLCO, all (damage) risks are treated as additional costs since theoretically the same amount could be paid for insurance to transfer these risks. Even if payments are not made for external insurance, we still bear these costs because we self-insure our risks internally. That means that alternatives with higher risks have lower HLCO values and appear less attractive. Additionally, in HLCO the decision maker can define his subjective limits for mean deviation risks (see Chapter 7.1.8). All alternatives that do not satisfy them are excluded automatically.

The same procedure is appropriate for optimizing maintenance of all subsystems because their useful lives are also probabilistic. They can also fail earlier than planned due to bad quality or wrong usage that accelerates their wastage. Usually, the probability of failure will increase with time due to wastage and obsolescence (or increasing usage because of higher traffic in the future).

Risks and chances in HLCO

By definition, damage risks represent potential damages D that could eventually be incurred as costs in the future with its likelihoods L . Therefore, damage risks could be treated as additional real costs. This means the damage risk R for a particular type of events of damage i in the year t is $R_{it} = L_{it} * D_{it}$.

Since damage risks are treated as additional costs in HLCO, it is assumed that in year t additional costs $C_{it} = R_{it}$ arise. This assumption is realistic because to insure the damage risk R_{it} it is necessary to pay the risk premium C_{it} for the insurance if available or self-insure it by setting up risk reserves C_{it} . Usually, the risk premium includes $C_{it} = R_{it}$ plus further costs and profits of insurers. Thus, one can discount them to consider the time value of money. Consequently, it is possible to calculate a “system life insurance” depending on its useful life and age similarly to human life insurance.

Theoretically, all future costs could be seen as risks referred to 0 € and all future benefits as chances referred to 0 € since their values are always probabilistic. Only risks and chances with the probabilities 1 such as realised past costs and benefits can be called costs and benefits.

5 Descriptive models

This chapter summarizes the basics of descriptive models. By definition, *descriptive models* are instruments that are able to selectively depict some economic processes. [45] They are used for qualitative or quantitative description of analysed real investment objects.

5.1 Investment object

Investment objects are economic goods that are leased or bought by investors for their usage. Investment objects can be all economic goods e.g., plots of land, assets, facilities, securities, patents, even planning by means of HLCO models, etc.. [46]

As mentioned above, both risk management and WLCC are used to optimize investments. Unfortunately, the investment objects optimized in risk management or WLCC are usually single projects or (sub-)systems but not the total investment program. However, optimizing single parts of the total independently of each other mostly leads to suboptimal solutions. There are many causes responsible for suboptimal results (see Chapter 3.7 profit versus profitability, and Chapter 7.2 dependences in aggregations).

To find the actual optimal solution, it is better if the investment object in HLCO is the total investment program. Only then we can really optimize our total results considering all costs, benefits, uncertainties, risks, chances and their dependences. Thus, analysing the total investment program we can minimize all risks thanks to the risk diversification. Usually the decision quality and the analysis costs will be the highest if we optimize the total system (e.g., the entire German railways) instead of its different subsystems separately from each other (e.g., trains or tracks).

Thus, the best way is to apply HLCO to the total investment program of the investor and not to its subordinate elements. However, HLCO is very flexible. It can optimize any single subordinate element, too. In fact, we even have to subdivide the total investment program in a breakdown structure in its subordinate elements and to calculate them separately from each other in order to optimize the total investment program. Afterwards, we should consider the dependences between all subordinate elements during the aggregation since they influence risks and chances.

Nevertheless, the reader must understand that HLCO analysis of a single event of damage is impossible since it is not an investment object. Rather all events of damage should be summarized as damage risks in damage probability functions.

Furthermore, some literature on WLCC suggests choosing single business functions as investment objects instead of single systems. The author does not share this opinion because business functions are not really investment objects. It is better to choose systems as investment objects because they mostly satisfy many functions simultaneously. For example, a system such as a train could increase transportation capacities for the output function and simultaneously improve safety, comfort and aesthetics. The author recommends considering all business functions in the subjective benefit matrix (see Chapter 11.2).

5.2 Breakdown structures

Breakdown structures are the most important descriptive models in HLCO. They break down the analysed investment object in its subordinate elements and structure them on their respective levels. Breakdown structures could and should be standardized to reduce the costs of analysis and to increase decision quality. [30, 31] In the following, the author presents standardized modules for breakdown structures to consider damage risks due to events of damage. There exist many types of events of damage that can be quantified by their likelihoods LE.

1. Types of events of damage
 - 1.1. Events of damage in transportation
 - 1.1.1. Events of damage in railways
 - 1.1.1.1. Accidents
 - 1.1.1.1.1. Crash
 - 1.1.1.1.1. Derailment
 - 1.1.1.1.2. etc.
 - 1.1.1.2. Late arrivals
 - 1.1.2. Events of damage in aviation
 - 1.1.3. Events of damage in seafaring
 - 1.1.4. Events of damage in traffic
 - 1.2. Industrial events of damage
 - 1.2.1. Events of damage in nuclear power plants
 - 1.2.2. Events of damage in chemical works
 - 1.2.3. etc.
 - 1.3. Medical events of damage
 - 1.3.1. Epidemics
 - 1.3.2. etc.

Every type of event of damage could have many different causes as single or combined triggers. These causes are also quantified by their likelihoods LC. Not all causes trigger events of damages. For instance, storms in uninhabited areas cause no damages. Besides, not all storms with equal wind speed lead necessarily, for example, to derailments.

2. Causes of events of damage
 - 2.1. Natural disasters
 - 2.1.1. Earthquakes
 - 2.1.2. Storms
 - 2.1.3. Floods
 - 2.1.4. etc.
 - 2.2. Human failures
 - 2.2.1. Insufficient professional education
 - 2.2.2. Ignored instructions and regulations
 - 2.2.3. Insufficient attention or falling asleep
 - 2.2.4. Insufficient safety policy and risk management
 - 2.2.5. etc.
 - 2.3. Malicious human behaviour
 - 2.3.1. Wars
 - 2.3.2. Terrorism or sabotage
 - 2.3.3. Espionage and hacking
 - 2.3.4. Vandalism
 - 2.3.5. etc.

Events of damage cause different types of damages that are described by their damage probability distributions (x: damage amount, y: probability of damage amount LD).

3. Types of damages
 - 3.1. Material damages
 - 3.1.1. Property
 - 3.1.2. Loss of production
 - 3.1.3. Environment
 - 3.1.4. Cultural heritage
 - 3.1.5. Image
 - 3.2. Humans
 - 3.2.1. Human lives
 - 3.2.2. Human physical and mental health
 - 3.2.3. Lost lifespan due to late arrivals

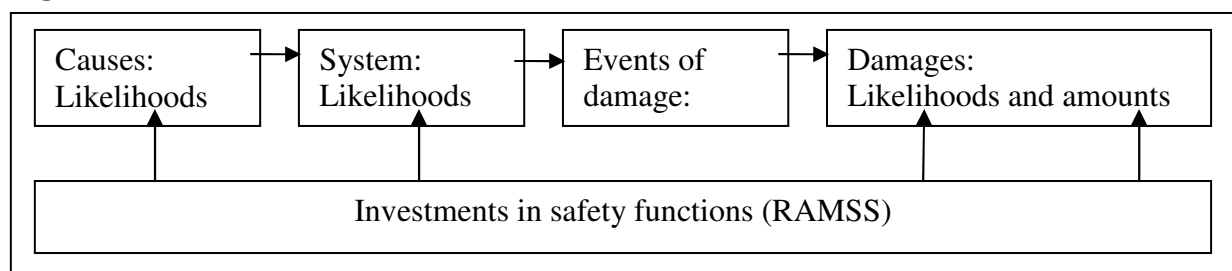
We can accordingly intervene in this chain (see Fig. 5.1) through investments in safety functions (RAMSS). Two ways of intervention are available for risk management. The first way tries preventively to reduce the likelihoods of events of damage LE by diminishing the likelihoods of its corresponding causes LC (e.g., set up buildings in more safe regions) or by increasing the system resistance to the causes (e.g., redundancies of safety relevant systems).

The second way intends to decrease damages during and after events of damage. Decreasing damages leads to beneficial changes in damage probability distributions. There are also two ways to influence beneficially damage probability distributions. First way is preventive and invests in safety systems such as airbags and seat belts before an event of damage to reduce damage amounts during the event of damage.

The second way invests in preparedness of emergency services and plans and early warning systems. We invest before an event of damage in their readiness for usage and additionally after an eventual event of damage in their usage to reduce damage amounts. The effectiveness of emergency services and plans is probabilistic and depends especially on its readiness and reaction time. Reaction time can be reduced significantly by means of the early warning systems.

Some safety investments (e.g., in security guards, safety engineers, technical safety experts and risk managers) use both ways and work cause-preventive before and damage-reducing during and after events of damage.

Fig. 5.1: Concatenation (modified from [1])



Insurances are a special case of preventive measures because they don't reduce damage amounts for society. Damages and with that damage risks decrease only for investors as policy holders and increase for insurance companies since a part of damage risks is transferred between them.

All investments in safety before events of damage are like fixed costs for the whole planning period. All investments in safety during and after events of damage plus realized damages could be seen like variable costs for the planning period which incur only if events of damage really occur.

4. Safety measures/functions

4.1. Preventive measures to reduce the likelihood of events of damage

4.1.1. Diminishing the likelihoods of causes of events of damage

4.1.2. Increasing the system resistance to the causes of events of damage

4.2. Emergency measures, different for different types of damages

4.2.1. Reducing the damage amount during events of damage

4.2.2. Reducing the damage amount after events of damage

4.3. Insurance

4.4. Self-insurance

6 Explanatory models

Explanatory models are applications of theories to more or less typical real processes. They are also used for prognoses because of the structural identity between explanation and prognosis. [45] The differentiation between description and explanatory models is more of theoretic interest. Thus, for practitioners description and explanatory models should be combined together. Therefore, in HLCO, all explanatory models are always integrated into breakdown structures as subordinate elements, e.g., employment and time dependent cost outcomes, learning and experience effects, capital costs, price escalation and inflation or deflation, exchange rates, depreciation and further tax savings, state subsidies etc..

6.1 Price escalation and inflation or deflation

Inflation means a persistent devaluation of the worth of money that increases the general level of prices. [47] *Deflation* is the opposite of inflation and means increasing value of money and decreasing the general level of prices. [48] Inflation or deflation is usually different for various sectors of industry and goods. However, price increases of certain goods are called (*price*) *escalation* but not inflation although the same principle is behind the both.

Inflation is a source of economic risk that should always be considered in the models. Otherwise, an apparently profitable investment could become unprofitable. The assumption that inflation is zero would be extremely unrealistic. The simplest assumption applies inflation in the same way to benefits and costs. [5, 49]

There are two methods of dealing with inflation:

1. We calculate future costs and benefits using nominal Euros, i.e., money amounts not adjusted to inflation. Afterwards we use a real interest rate (i.e., an interest rate adjusted to inflation). This method is the easiest if a time lag exists between future costs and benefits but no fixed prices. Unfortunately this method makes a very unrealistic assumption that inflation is constant. This is particularly unrealistic if the life cycle spans a very long period of time.
2. We calculate future costs and benefits in real Euros, i.e., money adjusted for inflation. For the adjustment we multiply all prices by a factor of 1 plus inflation rate implicitly assuming in our calculations the year of the initial investment as the base year. Afterwards we use a nominal interest rate, which is not adjusted to inflation. This method is the best, since it permits maximum flexibility in dealing with changes in inflation over time. [5, 50]

6.2 Taxes

Taxes should also be included in the models. Like the second method for inflation, the best method multiplies the taxed cash flows in real Euros by a factor of 1 minus tax rate. Additionally there are many legal ways of reducing taxes that are difficult to model. [5] Therefore, the taxes should be considered like the inflation/deflation as not deterministic but probabilistic factors. The probability distribution of tax factors could be derived from empirical data.

6.3 Risk acceptance and risk perception

This subchapter answers many frequently asked questions in regard to *objective risk acceptance* and *subjective risk perception*.

How safe is safe enough?

This question asks what level is the optimal risk level that describes the optimal residual risks and uncertainties that cannot or should not be avoided for technical, organizational or economic reasons. One should bear in mind that, despite investments in safety systems and insurance, residual risks and uncertainties that are impossible to avoid will always remain! These are always self-insured.

Since insurance companies cannot assess uncertainties, they are always a self-insured part of the investor's business risk. Of course, the investor's profit should be higher than residual risks and uncertainties.

For the affected third parties the state could insure residual uncertainties and risks with extremely high damages. If the potential damages are even too high for the state, the world community reinsures them. This can happen in cases of disasters when the vulnerability of the state exceeds its resistance.

The residual risks and uncertainties should be confronted with appropriate emergency plans. The application of emergency plans cannot influence directly the probability of causes but it can reduce the damage amounts. It is also very important that emergency management is applied as soon as possible after events of damage.

How to determine the optimal risk level?

Objectively, the optimal risk level cannot be formulated as a fixed number because it depends on the profit/profitability of the investment object. That means, considering all dependences, higher chances and benefits justify higher risks and costs. Therefore, in HLCO the optimal risk level is automatically determined with the optimal profit/profitability of the investment object.

Additionally, all stakeholders taking part in the decision process can define their subjective restrictions for every element and on every level of the breakdown structure. They can be expressed as fixed numbers, etc.. They are subjective because they depend on the subjective risk behaviour of the stakeholder. For instance, state authorities and the investor himself can limit maximal failure probabilities or damage risks. Decision models respect these subjective restrictions during the optimization.

Two groups of elements for damage risks should be considered in breakdown structures. The first one describes and explains objective damage risks that consider the objective market value of property/cultural heritage, and environment, economic value of human life and health etc.. The second group describes and explains subjective damage risks due to the subjective risk perception of events of damage by all involved stakeholders such as directly affected parties, media, customers, politicians, shareholders, lenders, etc..

The investor should consider with his eventual subjective restrictions both objective and subjective damage risks. The state authorities should derive their restrictions from the objective

damage risks. The state and its single citizens function like insurer. A part of damage risks caused by investors is transferred to them. As compensation for these negative external effects the state and its single citizens receive positive external effects such as more jobs instead of unemployment, higher inland revenue, better strategic and location factors etc.. This means that the state and its single citizens participate in the investment. The negative external effects of the investment are the initial and future costs to the state and its single citizens. The positive external effects of the investment are their benefits. Again, considering all dependences, higher chances and benefits justify higher risks and costs. This means that the state should use its restrictions to optimize its economic profit/profitability. Many norms, regulations and established approaches exist for that purpose. Their application and observance is mostly required by responsible state authorities.

How much are we willing to pay for safety? How much should we invest in safety?

The author suggests that when it comes to optimizing profit/profitability, the maximal residual risk is derived from objective damage risks by the state authorities and the minimal residual risk is derived from the sum of objective and subjective damage risks by the investor. Thus, we should be willing to pay for safety to achieve a residual risk within the closed interval between the minimal and maximal residual risk. These are our acceptability limits that specify the safety requirements.

The optimal residual risk is between the minimal and maximal ones and can be automatically calculated in HLCO by means of decision models. Thus HLCO can answer the questions “How much and how should we invest in safety functions?” and “What investment mix of safety measures should we choose?”

6.3.1 Marketing substitution

The author holds that giving appropriate consideration to subjective damage risks is very important because these are often much higher for the investor than the objective ones are. If the investor were able to describe, explain and forecast the subjective damage risks, he or she could justify higher investments in safety.

Unfortunately, in the literature there are no established statistical approaches for quantification of subjective damage risks as there are for objective ones. The few existing approaches are either very subjective or imprecise because of many unrealistic assumptions. Therefore, many scientists and practitioners avoid the quantification of subjective damage risks and prefer to rely only on established approaches for objective damage risks.

What does really happen in case of events of damage?

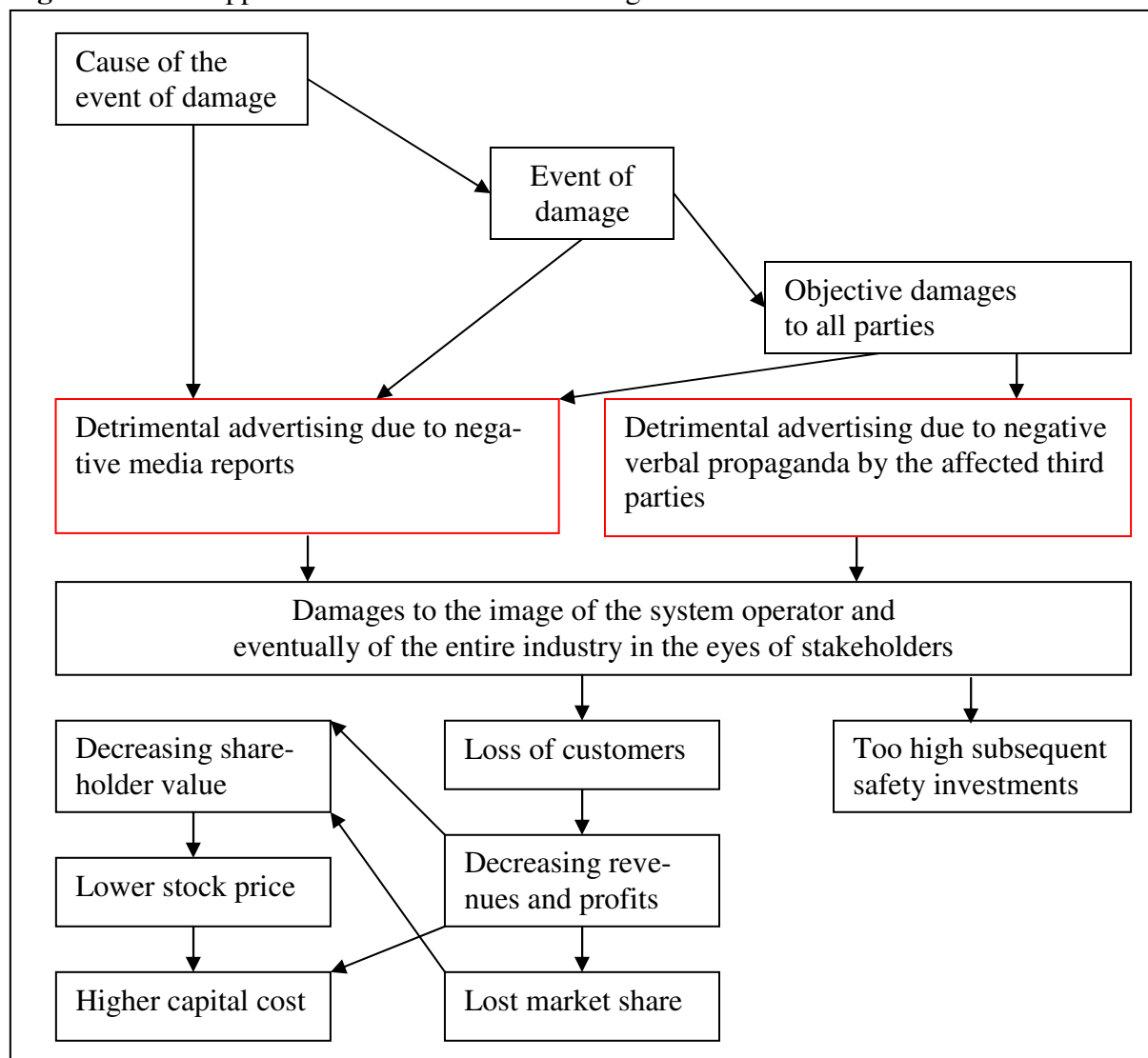
In case of events of damage the following processes occur (see Fig. 6.1). There is a cause for an event of damage. The probabilities for all causes are usually statistically known. Nevertheless, not every single cause leads to a real event of damage because the system has some resistance. The probabilities for system resistance to the causes are statistically or subjectively known. Events of damage cause damages to all stakeholders. The objective damage probability distributions are also known statistically for every element of causes.

The objective damages to affected third parties trigger the negative verbal propaganda that depends on their objective damages. Additionally, remarkable events of damage trigger negative media reports that depend on following factors: Objective damages and their probability,

probability for the type of event of damage, and probability of causes. The degree of responsibility of the system operator or the customers' self-responsibility and knowledge of the system are usually considered indirectly in reports about a concrete type of event of damage. For instance, for train accidents the responsibility of the system operator is very high and the customers knowledge of the system usually very low.

Negative media reports and verbal propaganda could be seen as negative marketing investments that are triggered by events of damage and paid for by society. They damage the image of the system operator involved. As negative external effects, they also cause damage to the image of all other system operators of similar systems. Thus the image of the whole industry could be affected by events of damage in a negative way.

Fig. 6.1: What happens in cases of events of damage



Damages to the image cause short-term and long-term loss of customers. Loss of customers leads to loss of market share and causes decreasing revenues and, with this, decreasing profit/profitability. Where joint-stock companies are concerned, loss of market share, decreasing revenues and profit/profitability reduce the shareholder value and lower the stock prices and with that the equity capital of the system operator. Thus the risks for capital lenders increase and lead consequently to higher future interest rates for borrowed capital and/or less credit capital available for future investments.

Additionally, most of the subsequent investments in the failed safety functions after events of damage are much higher than the previous ones. Often, they are even much higher than the optimum in order to satisfy authorities, calm media and customers and improve the tarnished image. Authorities could even forbid the further usage of failed products until significant safety improvements are made (e.g., the Concord plane crash). These safety investments could be regarded as beneficial marketing investments that are unfortunately too late and, because of the delay, too high.

The total damage to the system operator is the sum of the system operator's own objective damages plus objective damages to affected third parties which must be compensated and subjective damages to the operator's image due to subjective risk perception by stakeholders. These three elements should be considered in breakdown structures.

How does one describe, explain and forecast subjective damages?

Many safety scientists tried to explain customers' behaviour after events of damage in order to forecast subjective damage risks. Unfortunately, the results of such approaches are very unreliable. It is impossible to allocate loss of customers directly to events of damage because of many interfering factors such as economic trend, current demand, etc.. Particularly, the medium-term and long-term negative developments after events of damage cannot be re-traced.

Carrying out surveys is also very unreliable, because empirically, customers behave differently after events of damage than they claimed they would beforehand in interviews. Customers are more objective during interviews than after events of damage because afterwards they are influenced by negative media reports. [51] It would be better to interview professional experts such as psychologists, media and advertising experts etc.. However, their opinions are not representative. Therefore, many scientists and practitioners reject such approaches.

The author suggests another new concept. Instead of concentrating on customers' behaviour we should look at the hierarchy of damages (see Fig. 6.1). The central element for subjective damages is always the image of the system operator. Detrimental advertising causes damage to the image. All further negative effects such as losses of customers etc. are only consequences of the worse image.

To justify objectively higher investments in safety the author developed an explanatory model for subjective damages called *Marketing Substitution*. The idea behind it is very simple and realistic. We see the detrimental advertising after events of damage like negative marketing investments triggered by the system operator but paid directly by the media and indirectly by their mutual customers. Society expresses its subjective damages this way and makes the system operator suffer by internalizing, through negative publicity, the external costs that the system operator has caused.

The assumption is that negative marketing investments work like positive marketing investments and cause the same effects but with another algebraic sign. Thus, to neutralize the subjective damages we can substitute the negative marketing investments with positive ones made in the same way or we can substitute them preventively by investments in safety. Thus, investments in safety are investments in positive marketing!

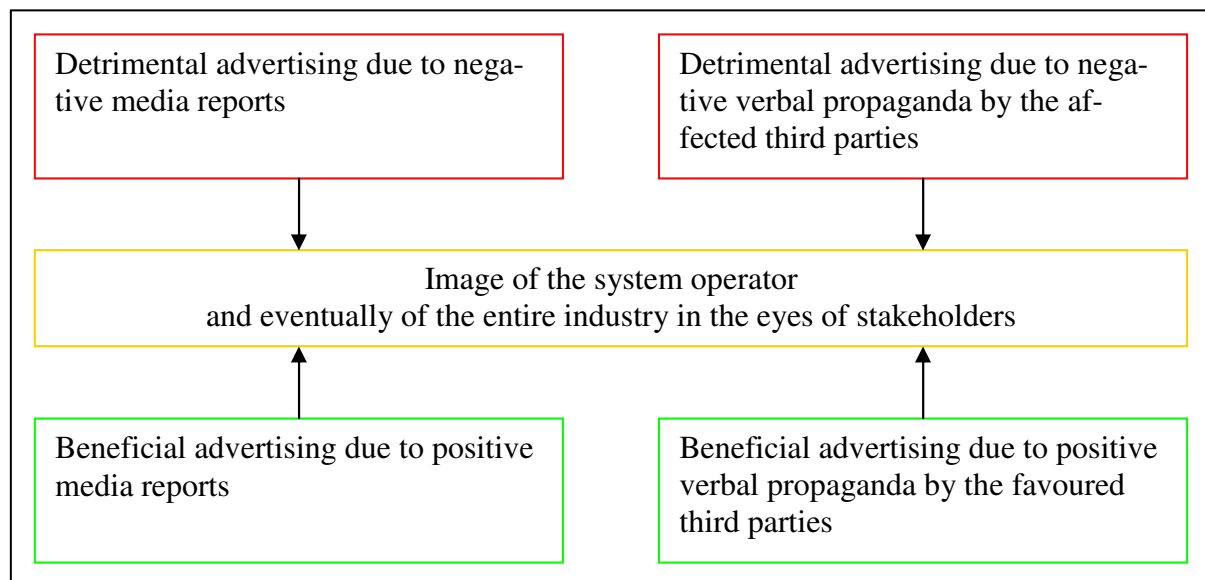
Marketing Substitution is applicable to safety, security, availability, that means to the value of human life and health, environment, cultural heritage, important people, human failure, malicious human behaviour such as terrorism, and so on.

How do negative media reports influence the image?

Subjective damages can only incur when the public knows / is informed about the event of damage. After an event of damage there are a lot of negative media reports. These reports are like detrimental advertising that damages the image of the system operator.

Therefore, to neutralize subjective damages, we theoretically have to make beneficial advertising in the same media (TV programs, newspapers etc.) and in the same way (the same broadcasting time, the same pages of newspapers) (see Fig. 6.2). It should also be the same date for marketing investments in order to account for the time value of money and changing prices for advertising over time.

Fig. 6.2: Neutralization of detrimental advertising by beneficial advertising



The prices for advertising at different broadcasting times for TV programs or for pages and lines in newspapers are usually well known. Current statistics exist for them in marketing. Thus we can calculate the costs paid directly by the media and indirectly by society for detrimental advertising. To do this, we multiply the amount of advertising (duration of broadcasting time, space in newspapers, etc.) by the corresponding advertising prices.

To describe, explain and forecast subjective damages, we just need to collect data about different causes and types of events of damage with their probabilities, objective damages with their probabilities, and amounts and prices of detrimental advertising. This is an indirect way to estimate subjective damages by substituting them with marketing investments in media advertising. According to *Marketing Substitution*, we assume that detrimental media advertising can be substituted by the beneficial advertising in the same way and that beneficial media advertising can be substituted with investments in safety. This assumption is relatively realistic.

How does negative verbal propaganda influence the image?

The public can also be informed without media reports by negative verbal propaganda. It can be assumed that negative verbal propaganda depends on objective damages. This assumption is relatively realistic. To estimate these subjective damages we also use Marketing Substitution. We assume that objective damages and direct charitable donations work similarly in regard to verbal propaganda but with opposite “algebraic sign”. Therefore to neutralize subjective damages it is necessary to donate the amount of objective damages in the same time (see Fig. 6.2). It should also be the same date for donations in order to consider the time value of money.

Consequently, after events of damage it is necessary to compensate objective damages and additionally donate the same amount to the affected people. The later the affected people get their compensation (for example after a long legal process) the higher objective and subjective damages are. This effect can be considered similarly to the time value of money by means of an interest rate. Accordingly to the substitution principle (subjective damages = objective damages), the same interest rate should be chosen for both subjective and objective damages.

According to Marketing Substitution, we can invest in marketing either before events of damage or afterwards to avoid subjective damages. We can also substitute these marketing investments with investments in safety since they improve the image, too.

Who finances detrimental advertising?

Our society finances detrimental advertising! Directly, the media companies pay for it. Indirectly, their customers do it. Customers pay money for it as it is in cases of newspapers. Additionally, they increase circulation of newspapers and TV ratings and with that the future advertising prices of these media.

Society expresses its subjective damages by means of negative media reports. It can realistically be assumed that the advertising prices are good indicators for the influence of the advertising on the stakeholders because in a free market economy with a fair competition they represent viewing, listening and reading figures, the spending power and with it the demand potential of the customers consuming this advertising. The advertising prices vary depending on the advertising medium, the media supplier, the TV broadcasting time or page in a newspaper.

(Sensational) news and advertising are products that media companies sell and live from. As in every supply chain media companies need some raw materials as inputs for their production. News and advertising are the outputs from the supply chain. Events of damage are such raw materials. The media interest in them is determined by the relationship between supply and demand. Thus, the rarer the events of damage and their causes, and the higher the objective damages, the greater the media interest is.

Objective damages are measured in media reports in human lives, which could additionally be differentiated in lives and injured health of children and sometimes of women, important and famous public persons, in damaged properties especially of third parties which are estimated monetarily, damaged environment, damaged cultural heritage etc.. Since the Marketing Substitution considers the influence of causes of events of damage, it is also appropriate for subjective damages due to human failures and malicious human behaviour such as terrorism, sabotage, espionage, hacking, and vandalism.

Moral aspects

All explanatory models for objective and subjective damages require not only scientific approval by academics and practitioners but particularly moral acceptance by society. To the opinion of the author the Marketing Substitution is not only objective and logical but it is also highly moral. Firstly, Marketing Substitution serves for objective and logical justification of higher investments in safety.

Secondly, it could be called “democratic”. As explained before society, i.e., the people finances indirectly the detrimental advertising and expresses by negative media reports its subjective damages. The media only help like election workers the people to express their subjective damages. Consequently, the data about detrimental advertising serves like election results that are “democratically” collected and represented by the Marketing Substitution.

6.3.2 Applications of marketing substitution

As mentioned in the previous subchapter Marketing Substitution justifies higher investments in safety. It is used to describe, explain and forecast subjective damages and can be applied to safety, security, availability, that means to value of human life and health, environment, cultural heritage, important people, human failures, malicious human behaviour such as terrorism, and so on. In this subchapter the attention will be given to both subjective and objective damages since subjective damages are triggered by objective ones.

Subjective value of human life and health

The value of human life and health is unlimitedly high from the idealistic/moral point of view. The author shares this attitude. However, we need to know a monetary value of life and health in order to optimize our investments in safety. If we invest insufficient resources in safety, it will have negative consequences on human life and health due to events of damage. Otherwise, it can realistically be assumed that excessively high investments in safety will waste our limited resources which will be lacking for other investments, for example in new lives / support for children. Limited resources are the basis, the prerequisite for both existing and new lives. Thus, generally formulated *risk management* is the management of limited resources for all existing and new lives.

How does one quantify the objective economic value of human life?

To quantify the objective economic value of human life we can use the gross national product (GNP) per person per year. For the *residual value of human life*, we estimate and aggregate the GNP for the period of the average residual life expectancy in our country. The *average residual life expectancy* is the difference between the average total life expectancy and the statistical average age of our population. There are very careful and continuously updated forecasts for the GNP per capita and the average residual life expectancy.

It is better to calculate the average residual life expectancy by means of the statistical average age of our population than to use the actual average age of endangered or damaged customers (e.g., in kindergarten or in old people’s homes) because we avoid this way the age discrimination and thus confirm with the human rights.

Of course, as good and fair hosts we should treat and protect all foreigners (e.g., tourists, foreign workers etc.) like our own citizens. Therefore, all endangered or damaged aliens are considered with equal rights in all our safety optimizations.

Value of intact environment and cultural heritage

The values of intact environment and cultural heritage are just two parts of the total value that we will inherit to future generations. To consider them in HLCO we use the subjective benefit matrix. Particularly, the chosen interest rate is very important for a fair consideration of their long-term effects on investment's profit/profitability.

Many books exist about the choice of the best interest rate from the economic and social points of view. In HLCO, the decision maker can choose different individualised interest rates for every element of the breakdown structure. The author recommends using variable but not generalized constant interest rates to consider the time value of money because it allows to distinct the optimal moments for our investments. Additionally, we could and should use for cash flows the real profitability of all following reinvestments, if known, instead of general interest rates to calculate HLCO more precisely.

How to consider subjective damages due to late arrivals?

The public can also be informed about too frequent delays without media reports thanks to detrimental verbal propaganda by affected customers. As in cases of accidents, it can be assumed that the detrimental verbal propaganda by affected customers depends on their objective damages. This assumption is relatively realistic. Thus, to estimate subjective damages we use again the Marketing Substitution for verbal propaganda like in cases of accidents. Again, marketing investments before or after events of damage can be substituted with investments in higher availability to improve the image.

Late arrivals are usually consequences of unavailability. Investments in higher availability will mostly increase safety and vice versa because there is a dependence between them. Thus, the benefits of such investments are higher availability and simultaneously higher safety etc.. Higher benefits could justify higher initial costs for investments in safety.

How does one deal with causes of events of damage such as human failures?

We should deal with human failures exactly the same way as with other causes of events of damage. We should analyse their total probability and subdivide them in their subordinate / secondary causes (sleeping, drunk, distracted, no knowledge, no experience etc.) with their corresponding probabilities. Afterwards, we should look for available safety measures and optimize the total investment mix by means of HLCO. Such measures could be teaching and training the personnel or replacing a human activity with an automatic, safer system etc..

How to deal with causes of events of damage such as malicious human behaviour?

In cases of malicious human behaviour such as terrorism, sabotage, espionage, hacking, and vandalism one is dealing with risks instead of uncertainties because we can use historical data to quantify them statistically. However, we should do it in a manner different than the usual one. For example, it is very difficult to deal with terrorism risks since their causes, the terrorists, adapt their behaviour flexibly and intelligently to the endangered systems.

In spite of this “prognosis problem” (see Chapter 7), we can use the historical data for prognoses of terrorism risks. We can get historical data about objective and subjective damages due to acts of terrorism in our country and for our industry (air transportation, rail transportation). We also know the market value of our industry in every past year. Thus, we can divide yearly damage in our country and industry through yearly market value of our industry in our country. This factor quantifies the damage risk due to terrorism. Then, we can use this risk factor for optimising investments in security by means of HLCO. Thus, HLCO answers the question “How much and how to invest in security?” To reduce the prognosis problem experts should adapt the past average risk values to the future planning period.

Investments in security could be stationary systems (e.g., walls, alarms, safes etc.) and mobile systems (e.g., security guards, secret service agents etc.) The dangerousness of terrorists as well as the effectiveness of security systems depends on their flexibility and intelligence. Therefore, mobile systems are usually more effective than stationary ones. Stationary systems, however, also have their advantages. However, their investment mix can be optimized by means of HLCO.

6.4 Internalization of external effects

The state as the representative of society has the task to internalize all positive and especially all negative external effects. The internalization is necessary for calculating fair prices and with that for the fair competition and the optimal allocation of limited resources. Some examples for national internalization standards are tax policy, environmental protection, social standards, safety requirements etc..

Since risks should be treated like costs, the state and society incur additional costs (e.g., lost lives and diminished health of citizens) due to risks associated with the operation of an investment object. These negative external effects should be internalized and not only reduced by means of safety requirements.

In the sense of HLCO and optimal allocation of limited resources, safety regulations should not dictate how and how much to invest in safety but only recommend maximally allowed residual damage risk of the total investment object. Then, the operator has to optimize the profit/profitability of safety investments by means of HLCO. The state should derive the minimal safety requirements from its objective risk acceptance.

Furthermore, the state could internalize its real objective damages by means of compensating fines that are fairly shared between damaged parties (state, families of killed or injured people, health insurances etc.). Additionally, society fines the investor through negative publicity that damages the image of the investor (see Marketing Substitution). Society internalizes this way its real subjective damages. Thus, the investor can derive additional safety requirements from the subjective risk perception of society.

Taxes should work according to the principle that the person who causes damage must bear the costs. They should be post priori without any generalizations such as a priori taxes. Generalized taxes have negative effects on risk preventive behaviour of system operators because they do not allocate damage risks individually to system operators. Thus, generalized taxes are contra productive in the sense of risk management and should be avoided. Furthermore, post priori taxes are more precise in the sense of the time value of money. Thus, they should be applied in the supply chain circa in the moment, the negative external effects really incur.

One way to reduce future costs is to minimize such inputs as raw materials, energy etc.. The reduction of inputs usually leads to a reduction of outputs such as environment damaging emissions. Thus, by reducing inputs of natural resources we simultaneously reduce outputs of emissions into the environment and accordingly improve the environment.

The state instruments for internalization of external effects such as emissions should consider flexibly the really used technology and enable in a fair way making profits with environment-friendly technologies. The best way to do this is to internalize all positive and negative external effects exactly according to the polluter pays principle, without any generalizations such as a priori taxes.

We use a car as an example. For manufacturing a car some (limited) natural resources are consumed as input and some emissions incur as output. These negative external effects should be internalized by post priori taxes for consumption of natural resources and emissions. Such taxes increase the manufacturing costs and consequently prices for customers.

A car consumes fuel that is a limited natural resource. Additionally the car causes emissions. In Germany we have a priori yearly taxes depending on horsepower of the car. Indeed, there is a correlation between horsepower, fuel consumption and emissions. This, however, depends particularly on the technology used in the car. Besides the final environmental damages depend on how much the car is really used. Thus, such a priori taxes are ineffective or even contra-productive.

Instead, we should apply taxes for (limited) natural resources directly to fuel consumed. This tax will increase fuel prices. Additionally, all foreign car drivers who usually do not pay a priori taxes in Germany depending on horsepower will pay the post priori tax for fuel. This is in the sense of a fair competition. The damages to roads depend also on driven kilometres that can be controlled and taxed once a year.

The real emissions depend on many factors such as fuel consumed and technology used. We should measure emissions directly and tax post priori. To reduce administrative costs, an indirect measurement could also be applied. For example, we can multiply driven kilometres or consumed fuel by the individualized average emission factor for this special type of cars. This factor should be published by the manufacturer and controlled by the state so that the customers identify them as their future cost drivers.

The post priori taxes could be invested to reduce or completely remove the real damages (e.g., by reforestation) or to subsidize the research and progress of ecologically desirable technologies. Generally, subventions should only reward for positive external effects.

This could be done by direct (e.g., payments) or indirect (e.g., lower taxes) subventions. Direct subventions such as investments in research for ecologically desirable technologies should be preferred. They are usually better than indirect subventions that only increase product sales of still immature ecologically desirable technologies. We should support directly the ecologically desirable technologies and not the manufactures of these technologies. Further examples for positive external effects are architecture, old trains and cars in museums. They increase our cultural heritage.

Most ideas for the internalization of external effects on the national level are usually very difficult to carry through politically and to put into practice. If these ideas are realized only on the national level and reduce the profit/profitability of invested capital but not the income of

employees they fail always on the long-term because the costs associated with them put the own national companies at a disadvantage in the international competition.

On a medium-term basis, the national companies would react with flight of capital and emigration of production to the “cheaper” abroad. The remaining companies would lose the competition on the long-term basis because of higher production costs due to the internalization. This means that on the long-term the internalization system will break down and the state will be forced to reduce its internalization standards, even if they are absolutely reasonable. We can observe this phenomenon in Germany now.

Some scientists demand international agreements for the internalization standards. However, it is extremely difficult to carry through any fair internalization standards on the international level because of clashing national egoisms (see the “game theory”). Many countries seek to attract international direct investments by selling low internalization standards like competitive advantages for their industrial locations. As the result of this egoistic policy the countries damage each other and the total humanity suffers. The global players play them off against each other to sabotage their national internalization systems. Consequently, the most international agreements are a poor sort of compromises that are put too late into practice. Very often these agreements are even ignored by some national industries to the disadvantage of the promise keeping nations (see the “game theory”).

7 Prognostic models

As mentioned in the previous chapter, explanatory models are also used for prognoses because of the structural identity between explanation and prognosis. *Prognostic models* are, by definition, complex approaches that make prognoses by means of a combination of different prognostic approaches. Prognostic models are used to try to take all possible influencing factors into account [52].

The results of prognostic models are either, directly, probability distributions of forecasted random variables or, indirectly, values of stochastic models that summarize probability distributions. For example, experts often estimate not the probability distribution, but its expected value and/or quantiles instead. For more details about different prognostic models, see the author’s master’s thesis [30, 53] and “Gabler Wirtschaftslexikon” [54].

Low data acquisition

Another challenge for HLCO is the lack of required historical input data. This makes it more difficult to use quantitative prognostic models. Underdeveloped specifications for data collection in databanks constitute one of the causes of low data acquisition. The short-term solution is to choose explanatory/prognostic models that do not require more data than it is available. In HLCO, suitable explanatory/prognostic models are selected using the Model Choosing Approach (see Chapter 11).

The long-term solution is to develop standard breakdown structures or even better Specific HLCO Approaches (see Chapter 11). On this basis, it is then possible to derive specifications for data collection in structured databanks and set up internal and external data warehouses. It is advisable to use OLAP databases instead of relational ones because OLAP saves all data in a multidimensional structure whereas relational databases save all data in two-dimensional tables. Consequently, queries in OLAP are more effective and efficient than in relational databases.

Unfortunately, many existing databanks must be restructured because data collected in the traditional way is of limited suitability for HLCO. The extraction of necessary details from often highly aggregated data is either practically impossible or very expensive. Consequently, setting up HLCO databanks is a long, costly process. Small investors, in particular, have a need to catch up because HLCO databanks are often too expensive for them. External public or private data warehousing services are a potential solution for such small investors.

Subjectivity versus objectivity in prognostic models

The less data available for prognoses, the higher the degree of uncertainty and the more subjective the estimation of the probability distributions. Usually, then a theoretical continuous probability function is chosen that is empirically known to be the most suitable one for the object being analyzed. Next, the chosen theoretical probability function is approximated to the given statistical data. Both the selection of a theoretical probability function and its approximation to the given objective data are more or less subjective and depend on the expert. Thus, a mixture of subjectivity and objectivity results.

Quantitative objective prognostic models are better able to deal with historical statistical data if such data exists. *Qualitative subjective prognostic models* are better able to deal with the uncertainty arising due to the prognosis problem.

The *prognosis problem* means there is no certainty that our observations and laws derived from the past will also be valid for the future development. Consequently, prognoses based on historical data may be wrong. For instance, this is particularly problematic where prognoses for new types of technologies and for damage risks due to climate changes are concerned. Additional research is required to develop new or improve existing prognostic models that consider current trends. Explanatory models for quantifying the prognosis problem and, with it, for quantifying the degree of uncertainty, may also be required.

The literature contains some quantitative objective prognostic models (e.g., the time series analysis, etc.) that extrapolate the future trend from the past observations in order to solve the prognosis problem. Unfortunately, they only partly reduce the degree of uncertainty arising due to the prognosis problem. Thus, even if all the required historical data is obtained, some uncertainty about future developments will remain.

The theoretical continuous probability functions interpolate and in particular extrapolate all other values of the random variable. Consequently, assuming a theoretical probability function we always change the statistical input data. Unfortunately, these changes of the input data are the source for many errors and opportunity for manipulations.

7.1 Statistic/stochastic models

Statistic/stochastic models are indexes that summarize frequency/probability distribution information in the form of characteristic numbers. As mentioned previously, they can either be estimated directly by experts or calculated from the frequency/probability distributions. Since the summarized information is easier to process, statistic/stochastic models are very important for the aggregation and decision models described in Chapters 7.2 and 8.

7.1.1 Statistic arithmetic mean and stochastic expected value

By definition, (*statistic arithmetic*) *mean* m is the average value of a random variable X .

$$m(X) = \sum_i (x_i * L(x_i)) / \sum_i L(x_i)$$

For a usual probability distribution with $\sum_i L(x_i) = 1$, the *statistic arithmetic mean* is a good estimator for the *stochastic expected value*.

$$m(X) \approx E(X) = \sum_i x_i * L(x_i).$$

The sums of x_i values weighted by corresponding likelihoods $L(x_i)$ are equal on the left and on the right of the mean. [55, 56]

$$\sum_i^{x < m} (x_i * L(x_i)) = \sum_i^{x > m} (x_i * L(x_i))$$

These areas represent deviation risks or chances which are in equilibrium for the mean.

$$\sum_i^{x < m} ((m(X) - x_i) * L(x_i)) = \sum_i^{x > m} ((x_i - m(X)) * L(x_i))$$

It is very important to understand that the mean considers all deviation risks and chances and is the equilibrium between them. Unfortunately, different probability distributions could have the same mean. Thus, the decision maker needs additional indexes as measures of dispersions/deviations to optimize deviation risks and chances.

7.1.2 Average deviation

The *average deviation* is a statistic measure of deviations with the following formula:

$$d = \sum_i |x_i - m| \cdot L(x_i)$$

The average deviation is very seldom used in practice because it is relatively difficult to calculate absolute values. [57] Its most important disadvantage is that it does not differentiate between negative and positive deviations. The average deviation sums them all together.

7.1.3 Variance and standard deviation

The *variance* provides information on the dispersion, i.e., the extent of the deviations of random variables around the mean. The variance of a probability distribution is given by the following formula:

$$\text{var } X = \sum (x_i - m)^2 \cdot L(x_i) = \sum x_i^2 \cdot L(x_i) - m^2$$

The variance or *standard deviation* is used interchangeably for ranking investment alternatives because the standard deviation is the squared root of variance.

$$\sigma = \sqrt{\text{var } X}$$

The greater the variance or the standard deviation, the more risky the investment. [12, 58] Again, the biggest disadvantage is that the variance and standard deviation do not differentiate between negative and positive deviations. They sum them both together. That means both negative and positive deviations are treated like risks. [59] This makes sense only for symmetric probability distributions or if all deviations are unfavourable.

Furthermore, extreme deviations are over-represented due to squaring. Even the root in the standard deviation does not correct this effect. Some scientists argue that over-representing extreme deviations is a favourable property because they are extreme risks. The author, however, holds that all risks should be treated fairly and equally.

7.1.4 Skewness

The *skewness* characterizes the statistic property of a frequency or probability distribution to be asymmetric. Different measures of skewness exist, all of which are used very seldom in practice. [60] The most popular formula of skewness uses the third moment:

$$s = E((x_i - m)^3) / \sigma^3$$

Decision makers never use the skewness alone, but together with the mean and the standard deviation instead. It provides additional information about the asymmetry, i.e., about extreme deviations if the mean and the standard deviation of available alternatives are equal. [59] Since it is relatively rare that alternatives have equal means and standard deviations simultaneously, use of the skewness is also relatively rare.

The advantage of the skewness is that by quantifying the asymmetry, it gives an indirect hint whether negative or positive deviations are greater. Thus, the skewness is appropriate for an indirect characterization of extreme risks. However, the biggest disadvantage is that the skewness does not really differentiate between negative and positive deviations. It still sums them all together. [59] Furthermore, due to third power extreme deviations are even more over-represented than in variance and standard deviation.

7.1.5 Lower and upper partial moments

The *lower partial moment* is a measure of failure. It sums up all risks of falling below the desired reference value of the random variable. This means all negative deviations to the reference value are weighted by their corresponding likelihoods and summed up. The lower partial moment is described by the following formula [59]:

$$LPM_m^1(X) = \sum_i \max[(m - x_i), 0] \cdot L(x_i < m)$$

The *upper partial moment* characterizes by the following formula all chances of exceeding the reference value:

$$UPM_m^1(X) = \sum_i \max[(x_i - m), 0] \cdot L(x_i > m)$$

The partial moments seem to differentiate between deviation risks and chances. Unfortunately, they don't really do it because referred to the mean the lower and upper partial moments are always equal for every probability distribution. Consequently, they are insufficient for quantifying the differences between deviation risks and chances referred to the mean.

The partial moments are related to the average deviation as follows:

$$d = LPM_m^1 + UPM_m^1 = 2 * LPM_m^1 = 2 * UPM_m^1$$

7.1.6 Failure probability

The partial moment of the 0th order is called the *failure probability*. It quantifies the likelihood of falling below the reference value. [59]

$$LPM_m^0 = \sum L(x_i < m)$$

It is a very popular and reasonable measure of risks. However, it does not consider the magnitudes of negative deviations.

7.1.7 p-quantile as measure of Value at Risk

Another very popular measure of risks is the *Value at Risk (VaR)*. For its quantification p-quantiles are used. The Value at Risk calculates the maximal reduction in value that is only exceeded with probability p. The calculations of p-quantiles are iterative and thus very time consuming and problematic. To simplify calculation of the VaR and reduce processing time, it is usually assumed that all random variables are normally distributed. In this special case, all random variables are completely described by the mean and the standard deviation without the skewness. [59]

7.1.8 Conditional expected value as measure of mean risk and chance

To recapitulate, all existing statistic/stochastic models such as the average deviation, variance, standard deviation, skewness and even lower partial moment do not really differentiate between risks and chances.

This is why the author chooses the *conditional expected value* as the measure of *mean risk and chance*. Though, its formula is known in mathematics, until now it has not been used directly as the measure of risks and chances but only indirectly as a factor hidden in the partial moments. Thus, to the knowledge of the author, the following application and interpretation of it in risk management are new.

The *mean risk* for a probability distribution is the lower partial moment referred to the mean and divided by the failure probability also referred to the mean. It is described by the following formula of the modified conditional expected value:

$$m_R(X) = \frac{\sum_i ((x_i - m) \cdot L(x_i) | x_i < m)}{\sum_i L(x_i < m)} = \frac{LPM_m^1}{LPM_m^0}$$

The *mean risk* quantifies the mean negative deviation from the reference value. For all cases if the random variable is lower than the reference value its negative deviations are on average equal to mean risk. In this formula the mean is the reference value. However, other reference values could also be chosen.

Analogously, the *mean chance* quantifies the mean positive deviation from the reference value, which is the mean in this formula, too. For all cases if the random variable is higher than the reference value its positive deviations are on average equal to mean chance. However, other reference values could also be chosen. The mean chance for a probability distribution is given by the following formula of the modified conditional expected value:

$$m_{CH}(X) = \frac{\sum_i ((m - x_i) \cdot L(x_i) | x_i > m)}{\sum_i L(x_i > m)} = \frac{UPM_m^1}{UPM_m^0}$$

In both formulas, the likelihood of the mean $L(x_i = m)$ is excluded from $\sum_i L(x_i)$.

The advantages of the mean risks and chances are that these formulas are absolutely universal. That means the values of mean, mean risk and mean chance are never equal for two different probability distributions. They objectively differentiate between risks and chances.

Furthermore, they consider extreme deviations in a very favourable, fair way for damage risk management without over-representing them by the second or third order like within the variance, the standard deviation, and the skewness. This fair representation of all deviations is the most important prerequisite for solving the “ $0 * \infty$ problem”. The “ $0 * \infty$ problem” deals with the optimization of investments in safety to reduce the risks of frequent events with low damages and of seldom events with extreme damages. It is impossible to answer the “ $0 * \infty$ problem” in general terms. Nevertheless, HLCO can find, by means of its decision models, the optimal mix of investments in safety to reduce all risks of the investment object, among other things also ones of frequent events with low damages and/or of seldom events with extreme damages.

The *average at mean risk* and the *average at mean chance* are derived on the basis of mean risks and chances. They quantify the values of the random variable at the distance of mean deviations from the reference value. Both of them are referred to the same reference value as the mean risk and chance. In the following formulas the reference value is again the mean:

Average at mean risk: $A_R(X) = m - m_R$

Average at mean chance: $A_{CH}(X) = m + m_{CH}$

The averages at mean risk and chance are very important for the aggregation and decision models described in Chapters 7.2 and 8.

7.2 Aggregation models

Aggregation models consider dependences between subordinate, narrowly defined random variables and summarize them into a superordinate, extensively defined multidimensional one. [61] *Multidimensional probabilities* are empirical or theoretical distributions that represent more than one random variable. [62] Multidimensional probabilities consider directly all dependences between different elements/random variables of the analysed investment object. If one analyses the whole investment object, all dependences are already internalized. If one analyses single subordinate elements separately, these “external effects” on other subordinate elements and vice versa should be internalized if possible, too.

The author has already identified three types of aggregation models:

- Aggregation of already realized values and of stochastic expected values by means of correlation coefficients
- Monte Carlo Simulation by means of correlation coefficients
- Aggregation to Net Terminal Value with Dependence Factors

One must always consider all dependences between all random variables. The dependences are particularly important in context of risk management because (mean) risks and chances depend on combinations of random variables.

7.2.1 Correlation analysis

In statistics, *correlation* denotes a more or less intensive relation of two random variables. [63] *Correlation analysis* quantifies the intensity of the dependences between random variables by means of correlation coefficients. [64] Summarized, dependences are always considered in the literature by means of correlation coefficients. There are many different correlation coefficients. However, the most popular one is the *linear product-moment correlation coefficient* with the following formula:

$$r_{xy} = \frac{1}{n} \sum_{i=1}^n \left(\frac{(x_i - m_x)}{\sigma_x} \right) \left(\frac{(y_i - m_y)}{\sigma_y} \right) = \frac{\sum_{i=1}^n (x_i - m_x)(y_i - m_y)}{\sum_{i=1}^n \sqrt{\left(\sum_{i=1}^n (x_i - m_x)^2 \right) \left(\sum_{i=1}^n (y_i - m_y)^2 \right)}}$$

Unfortunately, the linear correlation coefficient evidences many of the following disadvantages, which, in the author’s opinion, make it inappropriate for use in economic risk assessment:

Firstly, there are many nonlinear types of correlations but no selection criteria for choosing the appropriate correlation model. Therefore, mostly the linear model is used, leading to completely wrong results. It is advisable to always conduct at least a graphical test for the linearity of both variables.

Secondly, the linear correlation coefficient reveals many weaknesses and paradoxes that are explained by Sponsel in his online article [65].

Thirdly, the assumptions for the linear correlation coefficient are the same as for the standard deviation. It assumes that both random variables are normally and symmetrically distributed. Thus, it does not differentiate between negative and positive deviations.

Fourthly, all correlation coefficients measure only the intensity of the dependences between two random variables (and influences linked with them). Since for investments it is necessary to analyse the dependences between all random variables we will need very many correlation coefficients. One can summarize them in the *correlation matrixes* or compress their information in *matrixes with correlation factors*. [65, 66] Mostly, they provide additional information that is not integrated directly into the decision models and confuses the decision maker.

The author holds that correlation coefficients are very unfavourable for economic risk assessment due to the aforementioned disadvantages. Both the Aggregation of stochastic expected values and the Monte Carlo Simulation suffer from the disadvantages of correlation coefficients. Nevertheless, it is very important to consider dependences between random variables during aggregation.

Aggregation of Expected Values is relatively fast because its processing time grows linearly with every additional random variable. The disadvantage is the lower quality of results due to the lack of consideration of deviation risks and chances. The changes of deviation risks and chances due to dependences between the aggregated random variables could be considered only indirectly by means of correlation coefficients.

The Monte Carlo Simulation is a very powerful aggregation model that can universally handle very many random variables with any likelihood distributions. Unfortunately, the processing time of the Monte Carlo Simulation grows exponentially with every additional random variable and the quality of its results is also weakened by correlation coefficients.

To overcome the weaknesses of correlation coefficients, the author developed the Aggregation to Net Terminal Value with Dependence Factors as a third alternative. This could be seen as a further development of Aggregation of stochastic expected values by means of mean risks and chances.

7.2.2 Aggregation to Net Terminal Value with Dependence Factors

At first, one should ask oneself “Why do we need correlation coefficients?” and “Why do we perform correlation analysis?” What we really want to know is the time development of the investment object as the total depending on the combination/mix of its different elements and on the total market.

Actually, correlation coefficients are not really required in order to answer the main question. The only input data required is the statistical information pertaining to the random variables. This is the same information that is required for correlation coefficients. Then the time devel-

opment of the portfolio is calculated directly using m , m_R , m_{CH} . One simple example will be calculated in order to explain this new method called Aggregation to Net Terminal Value with Dependence Factors.

Example 7.2.1

This is an analysis of an investment program consisting of a mix of four alternatives. The alternatives could be either securities or assets. To the author’s knowledge, there are no other approaches that can aggregate securities and assets together. Usually, they are calculated separately because of their different structures. However, in practice, most companies invest one part of their capital in machines and another part in stocks. Thus, it makes sense to calculate them together within the investment program, but no one knew how to do this until now.

In our example, the alternatives A1 and A2 are stocks. We can see in the lines A1 and A2 the development of their stock prices. The alternatives A3 and A4 are assets, for example machines or buildings. Thus, one can see their cash flows in the lines A3 and A4. For instance, 60 € are invested in A3 and 1 € earned in the first year, 0 € in the second year and 1 € lost in the fifth year. The input data in the first table consists of statistics, i.e., all yellow marked values were empirically observed in the past.

- 1) Input data is inserted in the yellow cells in Table 1.
- 2) The “sum of the initial costs” is calculated.
 $I(t_0) = 50 \text{ €} + 90 \text{ €} + 60 \text{ €} + 100 \text{ €} = 300 \text{ €}.$
- 3) The “share” of every alternative in the total investment program is calculated.
 $\text{Share (A1)} = 50 \text{ €} / 300 \text{ €} = 0.166 \text{ etc..}$ The sum of all shares always equals to 1.

Fig. 7.1: Table 1: yearly cash flows

Alternative	Security/ Asset	Share	$I(t_0)$ €	$b(t_1)$ €	$b(t_2)$ €	$b(t_3)$ €	$b(t_4)$ €	$b(t_5)$ €	$b(t_6)$ €	$b(t_7)$ €
A1	Security	0.166	50	52	56	53	51	52	49	48
A2	Security	0.3	90	133	100	156	180	170	98	95
A3	Asset	0.2	60	1	0	1	1	-1	-1	-1
A4	Asset	0.333	100	8	-6	-4	5	7	9	9
Σ		1	300							

- 4) The “yearly cash flows per invested money unit of the initial costs $I(t_0)$ ” are calculated in Table 2. Here, it depends on the programmed formula whether the alternative is a security or an asset.

Examples for securities:

Cell A1; $b(t_1) = (52 \text{ €} - 50 \text{ €}) / 50 \text{ €} = 0.04$ (i.e., earned € / invested €)

Cell A1; $b(t_2) = (56 \text{ €} - 52 \text{ €}) / 50 \text{ €} = 0.08$ (i.e., earned € / invested €)

Cell A1; $b(t_3) = (53 \text{ €} - 56 \text{ €}) / 50 \text{ €} = -0.06$ (i.e., earned € / invested €)

Examples for assets:

Cell A3; $b(t_1) = 1 \text{ €} / 60 \text{ €} = 0.017$ (i.e., earned € / invested €)

Cell A3; $b(t_2) = 0 \text{ €} / 60 \text{ €} = 0$ (i.e., earned € / invested €)

Cell A3; $b(t_5) = -1 \text{ €} / 60 \text{ €} = -0.017$ (i.e., earned € / invested €)

- 5) Now the weighted sums of yearly cash flows per invested money unit of the initial costs $I(t_0)$ are calculated for every year $b(t_i)$. The weighting factors are the “shares”

from Table 1. The “weighted $\sum b(t_i)$ per invested Euro” represents the real cash flows of the total investment program considering all dependences between all alternatives.

Column $b(t_1) = 0.04 * 0.166 + 0.478 * 0.3 + 0.017 * 0.2 + 0.08 * 0.333 = 0.18$ (i.e., earned € / invested €)

Fig. 7.2: Table 2: yearly cash flows per invested money unit of the initial costs $I(t_0)$

Earned € / invested € in year t_i	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$	$b(t_7)$
A1	0.04	0.08	-0.06	-0.04	0.02	-0.06	-0.02
A2	0.478	-0.367	0.622	0.267	-0.111	-0.8	-0.033
A3	0.017	0	0.0167	0.017	-0.017	-0.017	-0.017
A4	0.08	-0.06	-0.04	0.05	0.07	0.09	0.09
Weighted $\sum b(t_i)$ per invested Euro	0.18	-0.117	0.167	0.093	-0.01	-0.223	0.013

- 6) Now we calculate in Table 3 for every alternative the mean, the average at mean risk, and the average at mean chance. Then we calculate the “weighted sum” of m , $A_{R,m}$ and $A_{CH,m}$. The weighting factors are again the “shares” from Table 1.
- 7) Afterwards we calculate the mean, the average at mean risk, and the average at mean chance for the “weighted $\sum b(t_i)$ per invested Euro”.
- 8) Now we compare the “weighted sum” of m , $A_{R,m}$ and $A_{CH,m}$ with the real values of the “weighted $\sum b(t_i)$ per invested Euro”. The comparison shows that they are equal for the mean but different for $A_{R,m}$ and $A_{CH,m}$.

These differences are caused by the dependences between the cash flows of the alternatives. The differences disappear only if all linear correlation coefficients of all alternatives are equal to +1. Otherwise, only the values of the mean are always equal. Thus the Aggregation of expected values/means is correct.

However, the “weighted sums of $A_{R,m}$ and $A_{CH,m}$ ” require corrective factors called “*Dependence Factors*” in order to match the real values of the “weighted $\sum b(t_i)$ per invested Euro”. For that we divide the “weighted $\sum b(t_i)$ per invested Euro” respectively through the “weighted sum” of m , $A_{R,m}$ and $A_{CH,m}$.

Dependence Factor $A_{R,m} = -0.084 / (-0.125) = 0.673$ [dimensionless]

Dependence Factor $A_{CH,m} = 0.147 / 0.173 = 0.847$ [dimensionless]

With the Dependence Factor $A_{R,m}$ we correct the “weighted sum” of $A_{R,m}$ and match the $A_{R,m}$ of the “weighted $\sum b(t_i)$ per invested Euro”.

$-0.125 * 0.673 = -0.084$ (i.e., earned € / invested €)

Fig. 7.3: Table 3: for statistics/historical data

Earned € / invested €	Mean m	$A_{R,m}$	$A_{CH,m}$	Median
A1	-0.006	-0.045	0.047	-0.02
A2	0.008	-0.328	0.456	-0.033
A3	9.91271E-19	-0.013	0.017	0
A4	0.04	-0.05	0.076	0.07
Weighted sum	0.015	-0.125	0.173	0.01
Weighted $\sum b(t_i)$ per invested Euro	0.015	-0.084	0.147	0.013
Dependence Factor [dimensionless]	1	0.673	0.847	1.333

- 9) Now we make the step from the statistic to the stochastic, i.e., from past frequency distributions to future probability distributions. Due to the prognosis problem probability distributions are always more or less different than the corresponding frequency distribution.

If we assume that there are (almost) no prognosis problems, i.e., the past data is absolutely valid in the future, then we can use directly the $A_{R,m}$ and $A_{CH,m}$ of the “weighted $\sum b(t_i)$ per invested Euro” calculated for the frequency distribution in Table 3.

Otherwise, we first calculate m , $A_{R,m}$ and $A_{CH,m}$ of the expected probability distributions for the alternatives. Then we calculate their weighted sums and correct them by multiplying with the corresponding Dependence Factors.

In the literature some scientists argue that the choice of the mean as the reference value for the most statistic/stochastic models as measures of risks and chances is an arbitrary assumption. [59] However, the fact that the mean is the only index with the Dependence Factor equal to 1 is, to the knowledge of the author, the first proof that its choice is not arbitrary. Since the Dependence Factor is always 1, the aggregation of the mean is always independent of risks and chances. Consequently, it is the only perfect reference value for risks and chances. Even the Dependence Factor of the median (see Table 3) can be unequal to 1 and is consequently less suitable as the reference value.

7.3 Net Terminal Value Method

The full name of the new aggregation model is “Aggregation to Net Terminal Value with Dependence Factors”. This subchapter explains why the Net Terminal Value is better for the aggregation than the Net Present Value. Additionally, some examples demonstrate how to calculate the Net Terminal Value.

7.3.1 Net Present Value

Net Present Value (NPV) is a model for temporal aggregation used in WLCC to consider the time value of money. In the NPV the discounted present value of cash inflow, i.e., of benefits $PV(B)$, is subtracted from the discounted present value of cash outflows, i.e., of costs $PV(C)$. Consequently, NPV quantifies the net contribution of the investment to the total profit/profitability by measuring its net value in today’s money. [12] The following formula is used for calculations of the NPV:

$$\begin{aligned} \text{NPV} &= \sum [\text{PV}(\text{B}) - \text{PV}(\text{C})] \\ &= (\text{B}_1 - \text{C}_1) * (1 + i)^{-1} + (\text{B}_2 - \text{C}_2) * (1 + i)^{-2} + \dots + (\text{B}_n - \text{C}_n) * (1 + i)^{-n} \end{aligned}$$

The interest rate i represents the ROI of the next best alternative as opportunity costs of capital for the analysed alternative. [67] The interest rate is synonymously referred to in the literature as the discount factor, discount rate, or Minimum Attractive Rate of Return (MARR). [12]

Unfortunately, the NPV method cannot calculate the real annualised profitability of the analysed alternative. Instead it calculates a factor that can be compared with the factors of other investments. The alternative with the highest factor is recommended by the NPV as “the best”.

7.3.2 Net Terminal Value

The *Net Terminal Value (NTV)* is very similar to the NPV. However, NTV values the cash flows of an investment not in terms of today’s money but in terms of what they will be worth in the future, at the end of the whole life. The following formulas of the NTV are similar to the one of the NPV:

NTV with a temporally constant interest rate:

$$\begin{aligned} \text{ntv} &= \sum_{t=1}^n ((\text{B}_t - \text{C}_t) * (1 + r)^{n-t}) \\ &= (\text{B}_1 - \text{C}_1) * (1 + i)^{n-1} + (\text{B}_2 - \text{C}_2) * (1 + i)^{n-2} + \dots + (\text{B}_n - \text{C}_n) \end{aligned}$$

NTV with a temporarily variable interest rate:

$$\text{NTV} = \sum_{t=1}^n ((\text{B}_t - \text{C}_t) * \prod_i (1 + i_t))$$

“The difference between NTV and NPV is that the former cumulates forwards to make a valuation at the end of the whole life, whereas the latter discounts backwards to a present day valuation.” [12]

The reason why the NPV method is so popular is the “optical illusion” that it makes possible to compare fairly alternatives with different life cycles. The NPV discounts all alternatives with different life cycles to the same present moment. Thus, it shows how much all future cash flows are worth in the present.

Nevertheless, the comparison of alternatives with different life cycles can lead to suboptimal choices. For instance, if the alternative with the highest NPV has lower cash flows over longer life cycles, then we cannot realize some attractive following reinvestments because of missing capital. Thus, it is necessary to move the attractive following reinvestment to a later moment or to raise additional loans. To raise additional loans is not easy because we already use the total credit plan. Thus, the choice of an alternative with lower NPV but higher cash flows in the first years could be much better for the chosen planning period and in the long-term. The fixed interest rate hides this disadvantage because it makes impossible to consider the following reinvestments with their real profit/profitability.

Summarized, the NPV does not calculate the real profit/profitability. It just makes relative statements whether the real ROI will be higher than the used interest rate. Of course, the higher the NPV the higher the positive difference between the real ROI and the interest rate.

Unfortunately, we still don't know the exact value of this difference. Therefore, the NPV has very limited meaningfulness. Additionally, it leads to questions about the optimal interest rate that are still the object of current scientific and moral discussions.

Using the NTV we can avoid all the disadvantages of the NPV because it makes possible to calculate the real profit/profitability. A fair comparison of alternatives is only possible if we discount them to the same moment in the future. Thus, the NTV forces us to compare the consequences of all alternatives for the same planning period. However, it is still recommended to annualize the real profitability of the planning period in order to make it comparable with other interest rates. For the NPV we don't need to annualize anymore.

Since we calculate the real profitability we don't really need an artificial interest rate. We could reinvest all positive cash flows using the real profitability of their following reinvestments. Moreover, for all negative cash flows we use either positive cash flows or the real interest rates of the raised loans. After we have calculated the real profitability we can derive the ROI from it and compare the ROI with all other artificial interest rates without making any individual recalculations. For example, we can compare the ROI with the individual and the social interest rates. If the ROI is lower, then we could avoid such investments.

Using the same interest rate, both the NPV and the NTV would recommend the same alternative as the best one. However, the NTV is much more flexible and powerful than the NPV because the NTV could be calculated with the real variable interest rates of the real following reinvestments or of credits instead of artificial fixed interest rates used in the NPV. Thus, we calculate the real profit/profitability that could recommend another alternative as the best one. This recommendation of the NTV is more logically consistent than the one made by the NPV. If the real following reinvestments are unknown we can still use the average real ROI of the investor or his desired ROI as the fixed interest rate.

7.3.3 Calculating real profitability

As mentioned above, we calculate the real profitability by means of the NTV.

The real profitability P_{total} for the whole planning period:

$$P_{total} = \frac{NTV}{I}$$

The real annualized profitability P :

$$P = \sqrt[n]{P_{total}} = \sqrt[n]{\frac{NTV}{I}} = \left(\frac{NTV}{I} \right)^{\frac{1}{n}}$$

Examples for calculating real profitability

All numbers in the following examples are deterministic in order to simplify their understanding. However, the same methods can be applied to stochastic calculations (see Chapter 7.2). Then we would perform three separated calculations with all numbers equal to m , or $A_{R,m}$ or $A_{CH,m}$.

Example 7.3.1

In the first example we invest 100 € in an asset and earn 50 € per year in the following four years until the replacement of the asset. The rest value of the asset is 0 € after the initial investment. The interest rate i is 10 % per year. Instead of the fixed interest rate i we can also use the positive cash flows for any following reinvestments with a real profitability different to P_i .

Fig. 7.4: Example 1: $i = 10 \% \Rightarrow P_i = 1.1$

€	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$
Cash Flows	-100	50	50	50	50
NTV		50	105	165.5	232.05

$$\text{NTV}(t_4) = 50 * 1.1^3 + 50 * 1.1^2 + 50 * 1.1^1 + 50 * 1.1^0 = 232.05 \text{ €}$$

$$P_{\text{total}} = 232.05 / 100 = 2.3205$$

$$P = 2.3205^{1/4} = 1.234$$

Example 7.3.2: Real profitability of leasing investments

The conservative financial policy forbids operation of production facilities through leasing contracts. However, leasing investments show many advantages and disadvantages so that in some situations their advantages could outweigh.

- For instance, the initial costs of leasing investment are much lower than the costs of acquisition investments so that expensive and risky credits could eventually be reduced or avoided.
- If the future cash flows are lower than rents, it is mostly easier to terminate the leasing contract than to sell the system. Thus, the deviation risks of profit/profitability are usually much lower.
- If we need the system only for a short period, it could be cheaper to rent it than to buy because hirers dimension their system for a longer period and have often lower costs per year.
- If we want to make the acquisition investment later because we wait for more capital or for a newer technology etc..

Therefore, we must treat leasing investments like all other acquisition investments in order to compare them in a fair way. Thus, only the first rent belongs to the initial costs I . All following rents are negative benefits. In the second example we rent the asset from our first example. The rent of 42 € per year is paid at the beginning of every leased year.

Fig. 7.5: Example 2: $i = 10 \% \Rightarrow P_i = 1.1$; rent = 42 € p.a.

€	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$
Cash Flows	-42	50-42=8	50-42=8	50-42=8	50
NTV		8	16.8	26.48	79.128

$$\text{NTV}(t_4) = 8 * 1.1^3 + 8 * 1.1^2 + 8 * 1.1^1 + 50 * 1.1^0 = 79.128 \text{ €}$$

$$P_{\text{total}} = 79.128 / 42 = 1.884$$

$$P = 1.8739^{1/4} = 1.17$$

Example 7.3.3

If the planning period is longer (or we want to compare with a longer alternative) it is necessary to adapt our shorter alternative by considering following reinvestments of produced cash flows until the end of the planning period. For instance, the planning period (or the other alternative) last eight years. Then we can replace, for example, our system. We can also use the remaining cash flows for any following reinvestment different to p_i . The initial costs C_2 of the following reinvestment in the fourth year are 90 €. Afterwards we will earn 55 € in the following four years. The rest value of the second asset is also 0 € after the initial investment.

Fig. 7.6: Example 3: $i = 10\% \Rightarrow P_i = 1.1$; reinvestment: $C_2 = 90$ €; $b = 55$ € p.a.

€	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$	$b(t_7)$	$b(t_8)$
Cash Flows	-100	50	50	50	50-90 =-40	55	55	55	55
NTV		50	105	165.5	232.05- 90=142.05	211.25	287.38	371.11	463.23

$$NTV_1(t_4) = (50 * 1.1^3 + 50 * 1.1^2 + 50 * 1.1^1 + 50 * 1.1^0) = 232.05 \text{ €}$$

$$NTV_2(t_8) = (55 * 1.1^3 + 55 * 1.1^2 + 55 * 1.1^1 + 55 * 1.1^0) = 255.255 \text{ €}$$

$$NTV(t_4) = NTV_1(t_4) - C_2 = 232.05 - 90 = 142.05 \text{ €}$$

$$NTV(t_8) = (142.05 * 1.1^4 + 55 * 1.1^3 + 55 * 1.1^2 + 55 * 1.1^1 + 55 * 1.1^0) = 463.230 \text{ €}$$

$$P_{\text{total}} = 463.230 / 100 = 4.6323$$

$$P = 4.6323^{1/8} = 1.211$$

If we compare two alternatives with different life cycles, the NTV forces us to think about a reinvestment for the alternative with a shorter life cycle if we still need a system for this operational function in the future. The total probability of events of damage will be then the same for both alternatives. For example, we need a system for an operational function for the next 20 years, and we can choose between two alternatives. The first alternative has the life cycle 10 years and the second one 20 years. We cannot say generally that the total probability of events of damage is lower for the first alternative because it is shorter. We will need to reinvest after 10 years in a new system for the next 10 years. Thus, the total probability of events of damage is the same if the both systems have the same probability of events of damage per year.

Nevertheless, if the initial costs of the second alternative are 1,5 times higher than for the first one and an event of damage happens in the first year we can expect to loose more in the second alternative. If it happens in the eleventh year we can expect to loose more in the first alternative. Only the HLCO analyses considering all initial costs and damage risks etc. can show us what alternative is really the best for the total 20 years. However, we cannot say generally that choosing a shorter alternative is better because we risk less initial costs or because the total probability of events of damage is lower during the shorter life cycle since it is necessary to consider the necessary reinvestment after the end of the shorter life cycle until the end of the longer one.

Example 7.3.4

If the planning period is shorter (or we want to compare with a shorter alternative) it is necessary to adapt our longer alternative. For instance, the planning period (or the other alternative) lasts six years.

Fig. 7.7: Example 4: $i = 10 \% \Rightarrow P_1 = 1,1$; reinvestment: $C_2 = 90 \text{ €}$; $b = 55 \text{ € p.a.}$

€	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$	$b(t_7)$	$b(t_8)$
Cash Flows	-100	50	50	50	50-90 =-40	55	55	55	55
NTV		50	105	165.5	232.05- 90=142.05	211.255	287.38		
Adapted NTV		50	105	165.5	232.05- 90=142.05	273.075	323.452		

$$NTV_1 = 50 * 1.1^3 + 50 * 1.1^2 + 50 * 1.1^1 + 50 * 1.1^0 = 232.05 \text{ €}$$

$$NTV_2 = 55 * 1.1^3 + 55 * 1.1^2 + 55 * 1.1^1 + 55 * 1.1^0 = 255.255 \text{ €}$$

$$NTV(t_4) = NTV_1 - C_2 = 232.05 - 90 = 142.05 \text{ €}$$

$$P_{total\ 2} = 255.255 / 90 = 2.8362$$

$$P_2 = 2.8362^{1/4} = 1.298$$

$$NTV(t_6) = (142.05 * 1.1 + 55) * 1.1 + 55 = 287.38 \text{ €}$$

$$\text{Adapted NTV}(t_6) = 142.05 * 1.1^2 + 90 * 1.298^2 = 323.452 \text{ €}$$

$$P_{total} = 323.452 / 100 = 3.23452$$

$$P = 3.23452^{1/6} = 1.216 > 1.211$$

This method of the *Adapted NTV* is the best if we want to adapt too long alternatives to the length of the chosen planning period or to compare alternatives with different life cycles. The Adapted NTV can be calculated in the same way for all following reinvestments of produced future cash flows. It is particularly in the sense of WLCC because we consider this way the whole life cycles of the initial investment and of all its following reinvestments since the whole life cycles are completely represented by the annualized profitability P_2 .

As we can see, the annualized profitability P for six years is a little bit higher than for eight years. This is not an error. This “optic” effect rewards the longer alternative for producing longer high annual profitability $P > P_i$. For instance, in the shorter alternative we would have after six years additional planning costs for the preparation of the following reinvestment alternative for the last two years. The magnitude of the reward/compensation is fair because it is the higher the longer the difference is between the life cycles. This optic reward or compensation is important for the fair comparison.

This method is the only fair one for comparison of alternatives with different life cycles using positive cash flows for real following reinvestments. If we use the cash flows for real following reinvestments, we mostly will have different life cycles. It would be only a seldom coincidence if all following reinvestments end exactly at the same moment as the planning period.

All other options are unfair and distort the results. For instance, if we ignore all cash flows after the sixth year, we would extremely discriminate the longer alternative because it would lower artificially its total and annual profitability. The discrimination is even more obvious if we make the cut after the fifth year because we reinvest $C_2 = 90 \text{ €}$ and get back only 55 € at the end of the fifth year. Thus, such a cut reinvestment would lower optically the profitability despite the fact that it is very profitable in reality and has $P_2 = 1.298 > P_i$.

Another option is to invest the cash flows of the shorter alternative with P_i until the end of the longer alternative. However, this method would discriminate the shorter alternative because we unrealistically assume that the profitability of cash flows after the sixth year is only P_i . In the same period we allow the profitability of cash flows of the longer alternative to be higher.

$$P = 1.211 > P_i$$

A third option is to discount down to the sixth year all later cash flows. However, this method would discriminate the shorter alternative because it increases artificially the profitability P_2 and thus P of the longer alternative. In the following two examples we discount down with P_2 or P_i .

Wrong calculations:

$$NTV_2(t_6) = 55 * 1.1^1 + 55 * 1.1^0 + 55 / 1.298^1 + 55 / 1.298^2 = 190.518 \text{ €}$$

$$P_{\text{total } 2} = 190.518 / 90 = 2.11687$$

$$P_2 = 2.11687^{1/2} = 1.455 > 1.298$$

$$NTV_2(t_6) = 55 * 1.1^1 + 55 * 1.1^0 + 55 / 1.1^1 + 55 / 1.1^2 = 210.955 \text{ €}$$

$$P_{\text{total } 2} = 210.955 / 90 = 2.3439$$

$$P_2 = 2.3439^{1/2} = 1.531 > 1.298$$

The forth method is to calculate the total profitability P_{total} or we maximise the profit for the real life cycles of compared alternatives. For example, we calculate the longer alternative for its eight years and the shorter alternative for its six years. This method discriminates the shorter alternative. We know that time is money and that capital can grow in the bank account with P_i or work in other following reinvestments with P_2 . Summarized, the crucial difference between alternatives with different life cycles is the fact that we give cash flows as future capital more time to work or to grow with different $P_2 > P_i$.

This is of course unfair and must be corrected before decision-making. Otherwise, it is necessary to make the less realistic assumption that all positive and negative cash flows grow with the lower artificial p_i . This unrealistic assumption is unfortunately still the usual praxis, especially for the NPV. It makes impossible to optimize the total investment program for the chosen planning period because it does not consider realistically the difference between cash flows at different moments.

Many books are written about the selection of the optimal interest rate i . It is still the topic of many scientific discussions. However, these books and discussions lose a big portion of their importance if we use the NTV and real following reinvestments for cash flows instead of the NPV with a fixed interest rate i .

Example 7.3.5

If we optimize the total investment program we can use the positive cash flows of other investments in the investment program (see Examples 3 and 4). It would not change anything because we select the best investment program altogether. However, if we compare only alternatives for one project, it is necessary to consider the required capital in the second and all following years.

For that we can calculate the required capital reserves in the first year by discounting back the “initial costs” of the following years. These capital reserves are a part of our initial costs in the first year, which are required and bound for this alternative. It is automatically considered with it that there is enough capital to cover all “initial costs” associated with the investment object in the following years. An example for an investment with initial costs incurring in many different years is a railway line.

Fig. 7.8: Example 5: $i = 10 \% \Rightarrow P_i = 1,1$

€	$I(t_0)$	$c(t_1)$	$c(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$
Cash Flows	-10	-40	-50	50	50	50	50
Adapted Cash Flows	-87.686			50	50	50	50
NTV				50	105	165.5	232.05

$$I(t_0) = 10 + 40 / 1.1 + 50 / 1.1^2 = 87.686 \text{ €}$$

$$NTV(t_6) = 50 * 1.1^3 + 50 * 1.1^2 + 50 * 1.1^1 + 50 * 1.1^0 = 232.05 \text{ €}$$

$$P_{\text{total}} = 232.05 / 87.686 = 2.646$$

$$P = 2.646^{1/6} = 1.176$$

As the following calculation shows, it would be a big difference if we mistakenly consider the second and third years as negative benefits.

Wrong calculations:

$$I(t_0) = 10 \text{ €}$$

$$NTV(t_6) = -40 * 1.1^5 - 50 * 1.1^4 + 50 * 1.1^3 + 50 * 1.1^2 + 50 * 1.1^1 + 50 * 1.1^0 = 94.4246 \text{ €}$$

$$P_{\text{total}} = 94.4246 / 10 = 9.44246$$

$$P = 9.44246^{1/6} = 1.454$$

Example 7.3.6

We optimize always the profitability of our equity capital, but not of the total capital. Thus, if in the previous example it is necessary to take credits in the second and third years with the interest rate of 15 % p.a., we treat credits as negative benefits and discount them up by $P_{\text{cr}} = 1.15$. The positive cash flows are used for paying back the credits as soon as possible and only the positive surpluses are discounted up by $P_i = 1.1$

Fig. 7.9: Example 6: $i = 10 \% \Rightarrow P_i = 1.1$; $P_{\text{cr}} = 1.15$

€	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$
Cash Flows	-10	-40	-50	50	50	50	50
NTV		-40	-96	-60.4	-19.46	27.621	80.3831

$$I(t_0) = 10 \text{ €}$$

$$NTV(t_6) = 80.3831 \text{ €}$$

$$P_{\text{total}} = 80.3831 / 10 = 8.03831$$

$$P = 8.03831^{1/6} = 1.415 > 1.176$$

Example 7.3.7

As we can see in Examples 6 and 7, credits increase the annualized profitability P . Unfortunately, they simultaneously increase risks m_R . This phenomena is called *Leverage Effect* in the literature. [68] Therefore, it is important to compare $A_{R,m}$ with the subjective requirements.

In the following we invest in the asset from the first example 10 € of our equity capital and 90 € of credits with the interest rate of 15 % p.a..

Fig. 7.10: Example 7: $i = 10\% \Rightarrow P_i = 1.1; P_{cr} = 1.15$

€	$I(t_0)$	$b(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$
Cash Flows	-10	-90	50	50	50	50
NTV		-90	-53.5	-11.525	36.746	90.421

$$I(t_0) = 10 \text{ €}$$

$$\text{NTV}(t_4) = 90.421 \text{ €}$$

$$P_{\text{total}} = 90.421 / 10 = 9.0421$$

$$P = 9.0421^{1/4} = 1.734 > 1.234$$

The examples shown above should help readers to understand real profit/profitability calculations in HLCO. This is a basic prerequisite for the decision models presented in Chapter 8.

7.4 Planning period

In practice, many decision makers avoid profitable long-term investments if they have negative effects on annual results in the first years and positive cash flows are expected much later. Often, they are more interested in high, stable, annual positive cash flows instead of no or low ones in first years and very high ones in last years of the planning period.

This behaviour seems to be irrational, but it is not. The decision maker is one of the stakeholders and pursues also his own interests such as safe working place, career and higher salary. To achieve his personal goals he has to satisfy other more important stakeholders such as his superiors, shareholders (i.e., shareholder value), lenders etc.. From this point of view his decision behaviour is rational.

Even many shareholders are not really interested in maximal long-term profitability because their investments are not long-term. Many decision makers and their superiors are also not interested personally in maximal long-term profitability because they will not work for the investor that long. They will retire or change the employer during the life cycle of the investment object. Thus, they prefer to optimize the investment object for their “individual planning period”.

The individual planning periods are unknown for single stakeholders (shareholder, planner, his superior etc.). The planning period is usually chosen subjectively by the decision maker. The author recommends that the management presets it because the planning period is a significant part of the management policy. The management has the key role. It is responsible to shareholders and is controlled by supervisory board. On the other hand, the working places of planners and their careers and salaries depend directly or indirectly on the management; simultaneously, the final results of the management depend on the motivation/interests of its employees including planners. Thus, the management is responsible and interested to satisfy with its results all stakeholders’ interests.

Since HLCO is very flexible it can consider all the wishes and interests of all stakeholders. For that the decision maker should optimize the entire investment program instead of single investments. If the decision maker is interested in high stable annual profit/profitability he should stabilize positive net cash flows by choosing the appropriate alternatives, even if their contributions to the long-term profit/profitability of the whole investment program are suboptimal.

This can be done for instance by using real NTV instead of NTV adapted to the shorter planning period (see Chapter 7.3.4). Alternatively, the decision maker could choose higher fixed interest rates. These higher discounting factors favour alternatives that generate higher positive cash flows in the first years.

7.4.1 Chaos theory

Talking about long-term planning periods we must confront the chaos theory which interpretations doubt the results of the long-term planning. The *chaos theory* is a mathematical theory that describes the behaviour of dynamic systems by means of deterministic non-linear differences or differential equations. The most important property of chaotic systems is an extremely high sensitivity of temporary paths/trajectories of variables. Slightly changes of initial or marginal conditions would cause totally different trajectories of variables which deviate increasingly with time from each other. As an imaginary example, we could think about the golf. A slight difference during the hitting of the ball (initial conditions) or a changed wind (marginal conditions) could cause extreme deviations of trajectories.

The possibility of chaotic dynamic was observed in economy as well as in ecology. The chaos theory could be especially important for the ecological policy. Some scientists expect that the application of the chaos theory to real systems would make long-term prognoses, plans and strategies useless because of temporarily increasing deviations of trajectories. [69]

The author disagrees with such a pessimistic and unrealistic interpretation of the chaos theory. We should not forget that the chaos theory deals just with deterministic chaos. Consequently, the only message of the chaos theory means that it is impossible to get deterministic outputs as absolutely exact prognosis if only the laws are described deterministically but the input data is not deterministic. Thus, if we use exact deterministic laws to process stochastic input data, we will always get of course stochastic output data, too. The more sensitive the chaotic system is, the higher the span of the probability distribution for the stochastic output data will be. However, what the chaos theory calls deterministic chaos, is simultaneously stochastic order for us, since we can still use the probability distribution of the output data for the further planning.

Therefore, the interpretation of the chaos theory, that long-term prognoses, plans and strategies are useless, is completely wrong. The chaos theory can only quantify the sensibility of deterministic laws to stochastic input data such as initial and marginal conditions.

7.4.2 Useful life, period of use

The *useful life* describes the period between the beginning of the operational/maintenance phase and the system failure e.g., due to events of damage or the wear. [70] In this definition the system failure due to events of damage is the only difference between the useful life and the *technical period of use* explained in the following paragraph.

The *period of use* of an investment object describes the duration of the operational/maintenance phase. [71] The *technical period of use* describes the period between the beginning of the operational/maintenance phase and the functional system failure only due to the wear without any events of damage. [72]

The *economical period of use* describes the period between the beginning of the operational/maintenance phase and the disposal of the system due to temporarily progressing main-

tenance costs because of the wear or due to increasing opportunity costs because of new technologies. [73] At the end of the economical period of use, a replacement reinvestment should follow if there are no better investment alternatives for the initial capital.

7.4.3 Optimization of investment objects with indefinite useful life?

If we perform HLCO analysis e.g., for the whole railway system in Germany we are confronted with unlimited useful life. We simply don't know when the useful life of the German railway system will end. Theoretically, it must even be unlimited since we want to use the railways for an indefinite period of time. If the investment object is, e.g., a total investment program we are always confronted with unlimited useful lives.

The solution is to choose the planning period (for example next 30, 50 or 100 years) for which we perform HLCO. The choice of the optimal planning period depends on its effects on the profit/profitability of the investment object and on the subjective preferences of stakeholders.

Furthermore, for HLCO calculations it is necessary to subdivide the investment object in a breakdown structure into its subordinate elements. Since all subordinate elements on the last levels have limited and normally different useful lives, we could orient for the planning period of the investment object on the longest economical period of use of its subordinate elements.

However, the author recommends choosing the optimal planning period depending on stakeholders' interests and considering simultaneously its effects on the profit/profitability of the investment object. The precision of prognoses is a part of their benefits. Therefore, the effects of the planning period on the profit/profitability of the investment object decides how long it should be since investments in a long-term planning must be treated in the same manner as any other investments.

We can say exactly the same about the degree of details. In fact we should ideally optimize the length of the planning period and the degree of details together because all costs and benefits of the planning process depend approximately on their mathematical product.

It is relatively easy to quantify the costs for planning, but for the benefits of the planning it is more difficult. The benefits are a better decision quality. An additional planning changes always the probability distribution of the profit/profitability and with that its m , $m_{R,m}$ and $m_{CH,m}$. The more we plan the more precise our prognoses are. The more precise our prognoses are the smaller is the span, $m_{R,m}$ and $m_{CH,m}$ of the probability distribution. In cases of certainty the span, $m_{R,m}$ and $m_{CH,m}$ would be equal to 0 and we would get not a probability distribution but a deterministic value with its probability equal to 1.

The economical periods of use of the investment object and its following replacement investment should be adapted to the (international) lifecycle of the product and the lifecycle of the industry for which it is used for in order to avoid investments in inordinately long periods of use.

8 Decision models

Decision models serve the optimal achievement of objectives. These objectives are not given arbitrarily. They must be either formulated directly by the stakeholders in the subjective benefit matrix or hypothetically assumed and explained by the decision maker. The decision models can be subdivided into selection and design decision models.

8.1 Selection decision models

Selection decision models help decision makers choose the optimal solution from the set of all known available alternatives. Selection decision models can be subdivided into decision rules under certainty, risk and uncertainty.

8.1.1 Decision rules under certainty

Decision rules under certainty are all models of linear optimization that are applied if all environmental conditions are known. [74] That means all probabilities are assumed to be equal to 1. Since the assumption of certainty with all probabilities equal to 1 is very unrealistic, optimal solutions found by means of linear optimization are also called “unreal decisions” in the literature. [74]

Together with the linear optimization, we can apply *sensitivity analysis* in order to quantify intervals in which variables are allowed to vary, so that the found optimal solution continues to be optimal. In sensitivity analysis, one or more variables are varied while all other variables remain constant. [75]

8.1.2 Decision rules under risk

Decision rules under risk are applied if objective probabilities can be assigned to environmental conditions.

Bayes’ decision rule chooses the alternative with the maximal mean m as the optimal solution. [76]

$$\max E(x) = \max m$$

However, Bayes’ decision rule does not consider the dispersion of the probability distribution, i.e., the deviation risks and chances. For example, probability distributions could have the same mean m but different standard deviations σ . Nevertheless, Bayes’ decision rule does not differentiate between such unequal alternatives. (see Chapter 7.1.1)

The *m/σ -principle* (alternatively *variation coefficient σ/m*) ranks all alternatives by maximizing the mean divided by the standard deviation. Thus it considers dispersion but unfortunately without differentiating between negative and positive deviations. (see Chapter 7.1.3)

$$\max \frac{m}{\sigma}$$

The *geometric mean* is only suitable for relative measures of economic performance such as the profitability and the ROI. [59] The basic idea behind it is that all earned money must be

reinvested at the end of every investment. The geometric mean calculates the average value of the profitability or ROI after an infinite number of reinvestments, assuming the same probability distribution for all reinvestments.

$$\max g = \max \sqrt[n]{x_1 \cdot \dots \cdot x_n}, \quad x_i > 0$$

The main disadvantage of the geometric mean is the mathematical fact that it makes no sense and has no economic interpretation if one or more values of x_i are lower than or equal to zero. The geometric mean can only be calculated for all $x_i > 1$. In practice, random variables x_i such as profitability also have values lower than or equal to zero, for example, due to extreme events of damage. For instance, profitability could be zero if the technical system is completely destroyed in an accident. The profitability could be even lower than zero if additional high damages are incurred by third parties.

Ignoring these values in calculations would lead to unreliable results in the sense of risk management because extreme events of damage are always imaginable for every investment. Even if their probabilities are very low, they are never equal to zero. Consequently, the geometric mean is not suitable for risk management. Additionally, the geometric mean cannot be used for aggregation. It can only be applied to the already aggregated probability distribution on the highest hierarchical level in breakdown structures.

Another very simple decision rule under risk is the *confidence index*, which compares in its formula the “best” two alternatives with the highest mean m using subjectively chosen p-quantiles. Usually, this is calculated using the 5 %-quantile $Q_{0.05}$ and the 95 %-fractal $F_{0.95}$. [77]

The confidence index entails the following disadvantages:

- First, it unrealistically assumes that all random variables are normally distributed.
- Secondly, it cannot be used if only one element in the breakdown structures of the compared alternatives evidences a difference greater than 25 % between $(m - Q_{0.05})$ and $(F_{0.95} - m)$. This limitation is the consequence of the assumption of the symmetric normal distribution. Unfortunately, in reality there is very often at least one random variable that does not satisfy this condition.
- Thirdly, due to the assumption of symmetric normal distributions the confidence index doesn't differentiate between risks and chances. It simply chooses, for every element of the breakdown structure, the greater of the two deviations $(m - Q_{0.05})$ or $(F_{0.95} - m)$.
- Fourthly, dependences between all random variables are not considered at all. That means all correlation coefficients are assumed to be equal to 1.
- Fifthly, due to the dependences not taken into consideration and different risks and chances, the best alternative could be a different alternative than the two alternatives with the highest mean m . Of course, it is possible to compare all pairs of alternatives, but such an analysis is relatively inefficient.

8.1.3 Decision rules under uncertainty

As already explained in Chapter 2, in cases of risk, objective probabilities are known. In cases of uncertainty, it is only possible to estimate subjective probabilities. But how does one deal with absolute uncertainty if one does not even dare to estimate subjective probabilities? In the literature, there are few decision models under uncertainty. Thus these decision rules substitute for the previous prognostic models and assume all probabilities in their own way.

The *Laplace decision rule* assumes that all possible events have equal probabilities. Then, according to Bayes’ decision rule, the alternative with the maximal mean is chosen. [78] Unfortunately, the assumption of equal probabilities is relatively unrealistic.

The *minimax decision rule* assumes that the probability of the worst value is equal to 1. [79] The *maximax decision rule* assumes that the probability of the best value is equal to 1. [80] Then, the alternative with the maximal worst or best value is chosen. The assumption of probabilities equal to 1 for the worst or the best value is even more unrealistic. The *Savage-Niehans decision rule* is like the minimax rule, but refers to the opportunity costs. [81]

The *Hurwicz decision rule* subjectively weights the worst and best values. Then the alternative with the maximal weighted average of the worst and the best values is chosen. [82] The assumption, that the probabilities of all other values between the worst and the best ones are equal to zero, is relatively unrealistic.

In cases of absolute uncertainty, the author recommends assuming that all values have equal probabilities as in the Laplace decision rule. This assumption is admittedly unrealistic. Nonetheless, it is still more realistic than the assumptions in the other decision rules under uncertainty. Afterwards, the same decision rules can be applied as for decisions under risk.

8.1.4 Relative Reinvestment Profitability and Absolute Reinvestment Profit

To overcome the weaknesses of the aforementioned decision rules, the author developed two new universal decision rules that can be applied under certainty, risk and uncertainty.

The **Relative Reinvestment Profitability (RRP)** with the following formula:

$$RRP = (A_{R,m} \cdot m \cdot A_{CH,m})^{\frac{1}{3}}$$

and the **Absolute Reinvestment Profit (ARP)** with the following formula:

If $m_{R,m} = 0$ and $m_{CH,m} = 0$, then $ARP = m$, otherwise

$$\text{If } m > 0, \text{ then } ARP = \frac{m \cdot m_{CH,m}^2}{m_{R,m}^2} = \frac{m}{m_{R,m}} \cdot \frac{m_{CH,m}}{m_{R,m}}$$

$$\text{If } m < 0, \text{ then } ARP = \frac{m_{R,m}^2}{m \cdot m_{CH,m}} = \frac{m_{R,m}}{m} \cdot \frac{m_{R,m}}{m_{CH,m}}$$

In the both reinvestment formulas, it is realistically assumed that at the end of the first investment, the returns on the previous investment need to be reinvested. We assume that all following reinvestments have the same probability function for profit/profitability as our first investment.

The dispersion of probability distributions is considered in the RRP by means of the average at mean risk $A_{R,m}$ and the average at mean chance $A_{CH,m}$. In the ARP the dispersion is considered by means of the mean risk $m_{R,m}$ and the mean chance $m_{CH,m}$. This way we describe the complete probability distribution by means of only three values: $A_{R,m}$, m , $A_{CH,m}$ in the RRP, and $m_{R,m}$, m , $m_{CH,m}$ in the ARP. Thanks to them, we consider all risks and chances objectively and differentiate between negative and positive deviations.

The reinvestment formulas describe the *risk/chance objective* and long-term decision behaviour. Nevertheless, one should bear in mind that the probability distribution analysed by means of the reinvestment formulas could be estimated more or less subjectively by means of the prognostic models. Thus, for the most part, we cannot avoid subjectivity completely and be absolutely objective.

The structure of the RRP is similar to that of the geometric mean. Unlike the geometric mean, the RRP considers by means of $A_{R,m}$ all risks, including for values of the random variable less than or equal to zero. Investments with $A_{R,m}(P) \leq 0$ would have $RRP(P) \leq 0$ and thus be extremely uneconomical.

Like the geometric mean, the RRP cannot be used for aggregation. It can only be applied to the already aggregated probability distribution on the highest hierarchical level in breakdown structures. The decision maker should be aware of this during the aggregation and use either the Monte Carlo Simulation or the Aggregation to NTV with Dependence Factors before applying the RRP.

Similarly to the geometric mean, the RRP works only for all relative measures of economic performance such as the profitability or the ROI. For the absolute measures of economic performance such as the profit the author developed the ARP. The ARP ranks all alternatives like the m/σ – principle because it is similarly constructed. Both the ARP and the m/σ – principle consider all deviation risks and chances. The advantage of the ARP, however, is that it differentiates between negative and positive deviations thanks to the mean risks $m_{R,m}$ and mean chances $m_{CH,m}$ (instead of the standard deviation σ used in the m/σ – principle).

The ARP is just a dimensionless ranking coefficient, whereas the RRP is in terms of real coefficients such as profitability. In summary, both the RRP and ARP reinvestment formulas permit a more realistic and fairer comparison of alternatives.

The lower the mean risk $m_{R,m}$ and mean chance $m_{CH,m}$, the higher the RRP. This means that if two investments have the same means m for profitability P , the RRP would recommend the alternative with lower deviations $m_{R,m} = m_{CH,m}$.

Example 8.1.1

$$\begin{aligned} m(P) &= 1.1 \text{ and } m_{R,m}(P) = m_{CH,m}(P) = 0.4 \\ A_{R,m}(P) &= 1.1 - 0.4 = 0.7 \\ A_{CH,m}(P) &= 1.1 + 0.4 = 1.5 \\ RRP(P) &= (0.7 * 1.1 * 1.5)^{1/3} = 1.0492 \end{aligned}$$

$$\begin{aligned} m(P) &= 1.1 \text{ and } m_{R,m}(P) = m_{CH,m}(P) = 0.1 \\ A_{R,m}(P) &= 1.1 - 0.1 = 1 \\ A_{CH,m}(P) &= 1.1 + 0.1 = 1.2 \\ RRP(P) &= (1 * 1.1 * 1.2)^{1/3} = 1.097 \end{aligned}$$

Professionals should only invest if $RRP(P) > 1$ because such investments are profit oriented.

For $RRP(P) = 1$ one would usually earn nothing.

Investments with $RRP(P) < 1$ represent highly speculative and loss-oriented decision behaviour because, over the long-term after reinvestments the profitability P will be less than 1. That means that less than 1 € will be earned for each Euro invested. For instance, investments in lottery tickets or casino games often have $0 \leq RRP(P) \leq 1$. However, they provide entertainment as an additional benefit.

As mentioned above, investments with $RRP(P) \leq 0$ should be avoided because such an investment behaviour is extremely loss oriented. $RRP(P) < 0$ means that, over the long-term after reinvestments, not only will the initial capital be lost, but third-party damages will also be caused. For example, if a nuclear power plant is built with very low safety standards, one can anticipate $RRP(P) < 0$ due to probable extreme damages to third parties.

Subjective requirements:

The assumption of risk neutrality in Bayes' decision rule is unrealistic, because every human decision maker has his or her own subjective risk acceptability limits. Some scientists claim that subjective risk decision behaviour is irrational, but it is not. It just appears to be irrational since the subjective risk acceptability limits are usually influenced by emotions. However, we should not forget that risk behaviour is always a part of the evolution process. The subjective risk behaviour and risk aversion is programmed in our genome since it is more advantageous in the long-term evolution process than objective risk behaviour is. The subjective risk behaviour enables us to decide faster and with lower consumption of resources. Therefore, the author recommends choosing the risks/chances objective reinvestment formulas combined with subjective requirements because they are realistic and practical. The decision maker can proceed as in the following:

The stakeholders should formulate their subjective requirements for the chosen decision rules. Investment alternatives that do not satisfy all subjective requirements are automatically excluded from the selection. The following subjective requirements could make sense for the RRP:

$$1.1. \quad P_{TD} = 0 \leq P_{RA} \leq A_{R,m}(P)$$

$$1.2. \quad 1 < P_{MG} \leq m(P)$$

$$1.3. \quad 1 < P_{MG} \leq RRP(P)$$

$$1.4. \quad 1 << P_{CA} \leq A_{CH,m}(P)$$

Where:

TD = write off damage

RA = subjective risk aversion

MG = minimal subjective goal ($P_{MG} = 1 + MARR$)

CA = subjective chance attraction

When determining risk acceptability limits P_{RA} for subjective requirements, one should consider that multiple decision makers in a group tend to take higher risks than one or a few decision makers.

In each formula, one could use a subjectively chosen quantil Q_L instead of $A_{R,m}$ and a subjectively chosen fractal F_L instead of $A_{CH,m}$. Both could be chosen independently from each other. For instance, the decision maker can subjectively adapt the RRP to the degree of uncertainty of the analysed probability distribution. The higher the degree of uncertainty is, the smaller L could be chosen for $Q_L(P)$ and the bigger L for $F_L(P)$. If the degree of uncertainty is very low one should tend towards $A_{R,m}(P)$ and $A_{CH,m}(P)$. Both the estimation of the degree of uncertainty and the choice of $Q_L(P)$ and $F_L(P)$ are made then subjectively by the decision maker.

8.2 Design decision models

To find the best mix of alternatives, one could calculate all possible combinations of alternatives and afterwards apply selection decision models to choose the best mix passively. Unfortunately, in the most practical decision situations this would be extremely expensive, very time consuming, and often even impossible.

That is why we use *design decision models* to pre-select the most promising mixes of alternatives actively before we apply the selection decision models. In summary, the main difference between selection decision models and design decision models is that the first passively select the best alternative from the set of the known alternatives whereas the second actively design the optimal solution, improving the mix of alternatives. [31] Design decision models can be subdivided into reference models and mathematical optimization models.

8.2.1 Reference models

Reference models are good examples of best practice. The decision maker could learn from and imitate them for his analysed investment object. [31] However, theoretical reference models are often unattainable ideals of the best practice that serve only for the rough orientation. For instance, all rules of thumb and recommendations are reference models. Reference models can be very helpful and usually require relatively little effort to apply. Unfortunately, they are not really adapted to the concrete decision situation and its specific conditions. Therefore, they cannot identify the best solution.

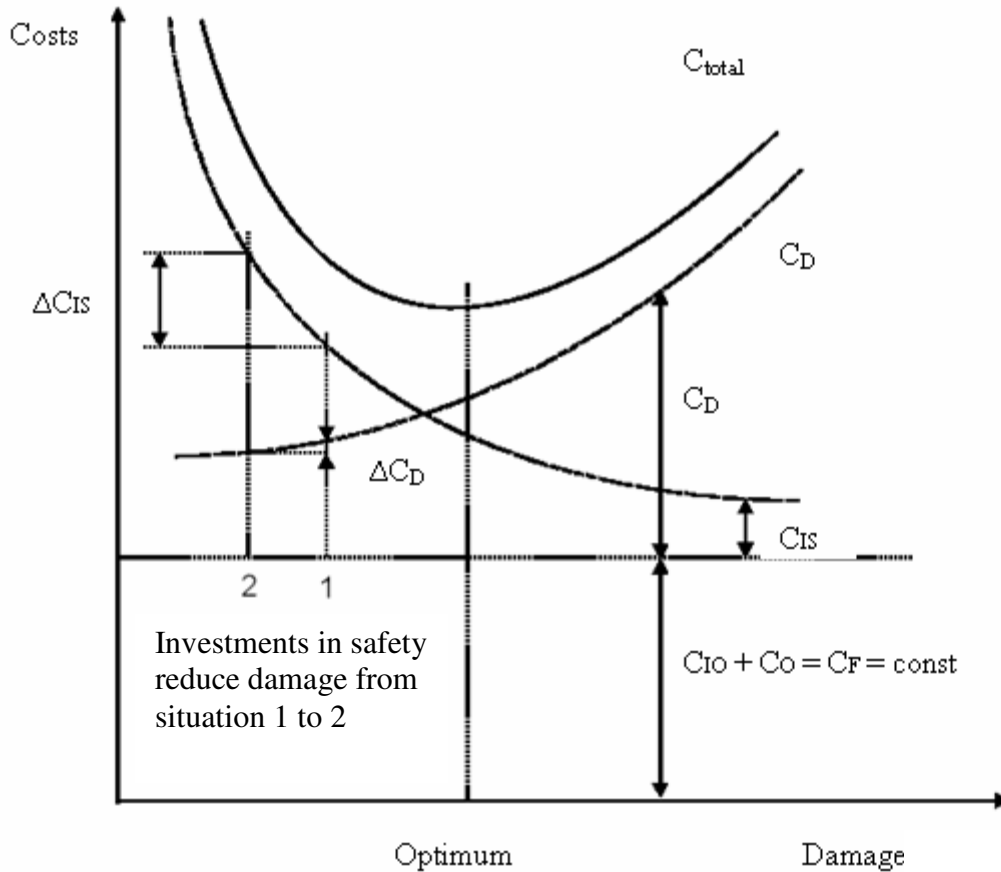
8.2.2 Mathematical optimization models

The category of *mathematical optimization models* encompasses all algorithms used in operations research and all heuristic and partly econometric models. [31] Unfortunately, most mathematical optimizations are *heuristic* because they optimize one or more parameters separately from all others but not all parameters simultaneously. Consequently, the associated heuristic solutions are admittedly usable but suboptimal.

The economic balance model as an example of mathematical optimization models

In the context of risk management, the following economic balance model is often mentioned in the literature.

Fig. 8.1: Relation between total costs and costs due to damages



The curve of the total costs C_{total} is the result of the combination of costs for investments in safety C_{IS} and costs due to damages C_D . Its economical optimum is the min C_{total} .

$$C_{total} = C_{IO} + C_{IS} + C_O + C_R = C_F + C_{IS} + C_D$$

Where:

C_{total} = Total costs

C_{IO} = Costs of investments in operational functions without safety functions

C_{IS} = Costs of investments in safety functions (i.e., cost share for integrated safety)

C_O = Costs for the operation of the investment object without damages

C_D = Costs due to damages

C_F = Costs of operational function without the cost share of damages ($C_{IO} + C_O$)

The popularity of this very good economic balance model is justified by its simple comprehensibility. However, the following more or less unrealistic assumptions weaken its results.

First, safety functions are mostly integrated into operational functions. Therefore, it is difficult or even impossible to differentiate between costs of investments in safety functions C_{IS} and in operational functions C_{IO} . [83]

Secondly, the economic balance model assumes a perfect market. That means the investor can finance all investments because the investor has access to unlimited available liquidity.

Thirdly, the economic balance model assumes that the decision maker is a *homo ratio* (i.e., “rational human being”). The *homo ratio* has immediate access to all necessary information and can process it without errors within an infinitely brief period of time. This means that the decision maker has absolute certainty about the outcomes of all investments. Therefore, the economic balance model is deterministic but not stochastic. All decisions are made by the *homo ratio* under certainty.

Fourthly, all investments are always made with cost steps equal to 1 €. In reality, initial costs of investments are usually different for different alternatives and much higher than 1 €. [84]

8.2.3 Simultaneous design decision algorithm

To overcome the significant weaknesses, described above, of the reference models and mathematical optimization models, the author developed a new design decision model called the *Simultaneous Design Decision Algorithm (SDDA)*. This algorithm actively designs individualized optimal solutions by simultaneously optimizing economic performance, risk reserves, mix of alternatives, and credit amount.

The SDDA could be seen as the further development of the economic balance model described in the previous Subchapter 8.2.2. It follows a principle similar to that of the economic balance model, but avoids the four assumptions explained in the same subchapter. Therefore, the SDDA is more realistic and more flexible. Usually, the optimum found by the SDDA will be to the right of the one found by the economic balance model (see Fig. 8.1). Consequently, one Euro invested in safety will save more than one Euro of costs due to damages. The optima found by the economic balance model and the SDDA will only be equal if capital resources are indeed available for all favourable investments. In that case, one invests until the last Euro invested in safety saves one Euro of costs due to damages.

To maximize the whole economic performance of the investment object, the SDDA chooses the best alternatives from all possible ones and simultaneously optimizes their shares in the investment program. The share of the selected alternatives is greater than 0. Simultaneously, the algorithm derives the optimal risk reserves for the initial costs of the optimal mix of alternatives and calculates the optimal credit amount. The optimization must be performed simultaneously because separate/heuristic optimizations lead to suboptimal results. The SDDA works recursively and iteratively using $m_{R,m}$, $m_{CH,m}$, $A_{R,m}$, $A_{CH,m}$, the Aggregation to NTV with Dependence Factors or Monte Carlo Simulation, and RRP or ARP with respect to subjective requirements.

Of course, for practical use, this complicated algorithm should be integrated as a module into a computer-supported software. However, in this dissertation only its logic is explained verbally and mathematically in the following in order to enable the reader to check its consistency and functionality.

Simultaneous Design Decision Algorithm (SDDA):

- 0) Choose the measures of economic performance and the selection decision models (e.g., RRP(P) and/or ARP(G)) which should be optimized.

- 1) Choose the equity capital I_e .
- 2) Choose the maximally allowed credit amount $B_{cr \max}$.

The outside capital B_{cr} is still a negative benefit, but not the initial cost.

- 3) Calculate maximal initial capital available for investments $I_{\max} = I_e + B_{cr \max}$.

The decision maker must either allow some deviations $\pm Z$ from I_{\max} or limit the processing time T_{lim} for iterative improvements or limit the number N of iterative improvements in order to avoid endless processing time during the iterative improvements in 17). It is also possible to use all three break-off criteria simultaneously.

- 4) Choose, for every investment alternative A_j , the minimal capital I_j required for the absolutely necessary business functions under competitive conditions to fulfil the minimal safety standards and to offer the minimal operational functions that are expected by authorities and customers. In alternatives that do not require minimal investments, $I_j = 0$.

The desired minimal liquidity reserves can be also chosen in this step as the minimal capital for the safe investment alternative A_r . A_r is, for example, depositing capital in a bank account with an interest rate of 3 % p.a..

- 5) Choose the cost step e.g., $\Delta I = 1 \text{ €}$ or $\Delta I = 100\,000 \text{ €}$ to reduce the processing time. The processing time for $\Delta I = 100\,000 \text{ €}$, for example, is ca. 100 000 times shorter than for $\Delta I = 1 \text{ €}$.

In practice, ΔI does not always exactly match the realistically possible ΔI_j of different investment alternatives A_j . In some cases, the minimally possible ΔI_j would be greater, in other cases, less than ΔI .

The single ΔI_j could also vary from cost step to cost step. This means that their values are not necessarily always constant.

To work realistically, one should always approximate ΔI_j to match ΔI . For example, the chosen $\Delta I = 100\,000 \text{ €}$, for the stock A_1 : $\Delta I_1 = 30 \text{ €}$, and for the asset A_2 : $\Delta I_2 = 120\,000 \text{ €}$. Then the adapted ΔI_j are $\Delta I_1 = 3\,333 * \Delta I_1 = 99\,990 \text{ €}$ and $\Delta I_2 = \Delta I_2 = 120\,000 \text{ €}$.

- 6) Calculate for all A_j : $I_j = I_j + \Delta I_j$.
- 7) Calculate for all A_j the additional benefits ΔB_j per the additional cost step ΔI_j .

The safe investment alternative A_r is in this step also one of the analysed investment alternatives A_j .

Theoretically, if $\Delta I = 1 \text{ €}$, then $\Delta B / \Delta I = B'(I)$. In this case, one calculates $B'_j(I_j)$ and $B'_r(I_r)$.

- 8) Choose the best cost step ΔI_j with $\max \Delta P_j = \Delta B_j / \Delta I_j$.

If $\max \Delta B_j / \Delta I_j = \Delta B_r / \Delta I_r$, then continue with 18).

- 9) Set back the other not chosen alternatives $I_j = I_j - \Delta I_j$.

One should first save $\Delta B_j / \Delta I_j$ of the other not chosen alternatives in order to reduce the processing time for recalculations in the next cost step in 6) and 7).

Choose additionally for the further analyses all alternative cost steps ΔI_j with $I_{\max} - A_{R,m}^a(\sum I_j) < \text{not chosen } \Delta I_j$ and set back each time the other not chosen alternatives $I_j = I_j - \Delta I_j$. These directions of cost steps will also be analysed completely until the end of the algorithm in order to avoid failure to identify the best investment program because there is not enough initial capital for the not yet chosen alternatives in the next cost step.

The upper index a means that the value is calculated considering all dependences during the aggregation either by means of the Monte Carlo Simulation or by means of the faster Aggregation to NTV with Dependence Factors.

- 10) Calculate the minimal risk reserves $I_{r \min} = m_R^a(\sum I_j) = A_{R,m}^a(\sum I_j) - m(\sum I_j)$.

- 11) Calculate the real risk reserves $I_r = \max [0; I_e - m(\sum I_j)]$.

- 12) Calculate the required credit amount $B_{cr} = m(\sum I_j) + I_r - I_e$.

- 13) Calculate the measures of economic performance for $m\sum I_j + I_r$ considering B_{cr} .

If one of the subjective requirements is not satisfied, then set back the last chosen alternative $I_j = I_j - \Delta I_j$. Afterwards, choose in 8) the next best cost step with the next best $\max \Delta P_j = \Delta B_j / \Delta I_j$. The other mix could satisfy the subjective requirements because of changed dependences.

- 14) Save the results (measures of economic performance, $I_{r \min}$, I_r , all I_j , $m\sum I_j$, B_{cr}).

- 15) For $m(\sum I_j) + I_{r \min} < I_{\max} - Z$, continue with 5).

For $m(\sum I_j) + I_{r \min} = [I_{\max} - Z, I_{\max} + Z]$, continue with 18) if 19) is not done yet, otherwise continue with 21).

For $m(\sum I_j) + I_{r \min} > I_{\max} + Z$, continue with 16).

- 16) Set back the last chosen alternative $I_j = I_j - \Delta I_j$.

The other not chosen alternatives have already been set back in 9).

- 17) Calculate a new smaller cost step ΔI which does not lead to the exceeding of $I_{\max} + Z$ in 15).

$$\Delta I = I_{\max} - m(\sum I_j) - I_{r \min}.$$

The $I_{r \min}$ used in this formula is still the same as in the previous step 15) and 10). This time, however, all I_j have the set back values from the previous steps 9) and 16).

If $\Delta I < X$ €, then continue with 21), otherwise continue iteratively with 6). The limiting value X can be chosen by the decision maker (e.g., $X = 1$ €). If $\Delta I < X$ € the decision maker is satisfied with the found solution and breaks up the iterative improvements.

18) Choose the best investment program with the maximal measures of economic performance.

19) Set back all $I_j = I_j - \Delta I_j$ of the provisionally best investment program chosen in 18) by reducing them with their respective last chosen cost steps ΔI_j .

This is done as a fine-tuning to check whether the optimal investment program is within the interval of the last respectively chosen cost step ΔI_j . For example, for $\Delta I_1 = 3\,333 * \Delta i_1 = 99\,990$ € with $\Delta i_1 = 30$ € approximated to $\Delta I = 100\,000$ €, the optimal investment program could be overlooked if it is between two cost steps, for instance at $60\,000$ € = $2000 * \Delta i_1$.

20) Choose a new smaller cost step $\Delta I = y$ € (e.g., $\Delta I = 1$ €) or $\Delta I = \Delta I / z$ and continue in 6). The values y or z can be chosen by the decision maker.

21) Chose and present the results for the best investment program (optimal measures of economic performance, $I_{r\,min}$, I_r , all I_j , $m\sum I_j$, B_{cr}).

22) End of the algorithm.

The SDDA is suitable for optimization of all investments in safety and operational functions. This design decision model is, in conjunction with the universal HLCO approach (see Chapter 11), the solution for the main objective of the dissertation which is “to generate a model to evaluate the costs for safety technology versus costs for emergency management from the viewpoint of LCC” [Prof. Pachl]. All investments in safety technology, in emergency management and in operational functions are elements in the set of all available alternatives. The SDDA, as an integral part of the Universal HLCO Approach, evaluates not only their costs but also all of their consequences and optimizes their mix by maximizing the economic performance of the investment object. For this purpose, every investment object is treated like the whole investment program.

8.2.4 Optimal replacement investment and moment

Two of the questions that are still insufficiently answered in the context of WLCC are “How does one choose optimal replacement investments, and how does one choose the optimal moment for replacement investments?” [85] The SDDA is the answer to these questions.

To react flexibly to changing risk environment and to improve annual investments, the HLCO analyses should be carried out or updated iteratively once a year. Every time one repeats HLCO, one can and should add all eventual replacement investments to the set of available alternatives. For replacement investments, one should proceed as follows:

If the old investment object is still expected to produce positive net cash flows, one should consider these positive benefits, lost due to the replacement investment, as additional negative cash flows of the replacement investment. These would diminish the profit/profitability of the

replacement investment.

If the old investment object is expected to generate negative cash flows in the future, one should consider these negative benefits, avoided thanks to the replacement investment, as additional positive cash flows. These would increase the profit/profitability of the replacement investment.

One should also consider net cash flows due to the disposal. The disposal could be a positive cash flow if one can resell the used investment object. The resale price of the used investment object could be estimated or accounted for by means of depreciation. These additional positive cash flows and the eventually planned and avoided negative cash flows for recycling should be considered as positive cash flows of the replacement investment. Sometimes there are no cash flows if one just discards the old investment object in the trash and no internalized external effects occur due to this trash.

Afterwards one calculates the real profit/profitability of the replacement investment considering as usual all dependences and compares it with other alternatives. As usual, the best mix of alternatives with the optimal profit/profitability should be chosen. If other alternatives from the set of all available ones still have higher profit/profitability, then one chooses them and postpones the replacement investment until a later moment. When this later moment arrives, one can proceed in the same manner (see Example 7.3.3 in Chapter 7.3.4).

9 General comments

This chapter contains useful comments regarding many frequently asked questions and potential problems within the context of risk management and WLCC that are currently detrimental to acceptance of risk management and WLCC. The author explains these in the interest of a better understanding of HLCO and suggests some new or improved solutions.

9.1 Trends in HLCO

In the future, the progress of HLCO will be influenced by the following trends:

1. A trend toward avoidance of overhead and allocation of all investment consequences (more) exactly to their respective causes, directly and without any generalizations, according to the principle that the person or element that causes damage must bear the costs.
2. A trend reflecting a change in decision behaviour away from passive selection and purchasing toward actively designing a tailor-made investment object thanks to cooperation within the supply chain.
3. A trend toward dealing with all investment consequences by predicting them a priori instead of controlling them post priori.
4. A trend toward estimating all investment consequences using quantitative prognostic models instead of qualitative ones or, better yet, by using qualitative and quantitative models together.

The current limits for these trends are determined by their profit/profitability. However, scientific progress and progress in information and communication technologies are continuously improving their profit/profitability by increasing benefits and reducing costs associated with the HLCO analyses.

9.2 Optimal damage risk contingents for subordinate elements

In practice, one is often confronted with the issue of how to subdivide the damage risks of the investment object into optimal *damage risk contingents* for its subordinate elements. Usually, damage risks of the investment object must be less than or equal to the maximally allowed acceptability limits: $R_{\text{total}} \leq \max R_{\text{total}}$ for the total investment object and eventually $R_i \leq \max R_i$ for its single subordinate elements i ! The maximally allowed damage risks are dictated by the standards or by the internal safety policy of the investor.

Frequently, an event of damage can only occur if many preventive safety mechanisms fail simultaneously (the so-called “cheese-hole principle”). Thus, there will be no event of damage if one of the safety mechanisms does not fail. This fact should be considered when it comes to safety investments.

HLCO is the solution to the problem of optimal damage risk contingents. Applying it, we choose or design the investment object with the optimal profit/profitability. This is automatically the investment object with the optimal damage risk contingents for its subordinate elements. All investments that fail to meet the acceptability limits ($R_{\text{total}} \leq \max R_{\text{total}}$ and eventually $R_i \leq \max R_i$) are excluded from the set of available alternatives and thus cannot be chosen.

9.3 HLCO-derived conclusions for manufacturers

Another practical question is: “What conclusions could manufacturers derive from HLCO if they knew that investors use it to optimize their investment programs?”. Manufacturers can use HLCO to increase the attractiveness of their products in comparison with products made by other competitors. [37] Knowing how investors calculate and optimize their profit/profitability leaves manufacturers with two options: reducing initial costs and/or increasing benefits for their customers.

The prices are simultaneously the biggest share of the initial costs for investors. Reducing prices means reducing manufacturing costs if the manufacturers still expect constant profits. Lower prices are still the most popular method among manufacturers because, unfortunately, many investors select their investment object only according to minimization of initial costs. To reduce discrimination due to eventually higher initial costs of investments optimized by HLCO, the existing laws for placing public orders should be improved.

Increasing benefits means improving the cost and benefit properties of the product. The *cost properties* are for instance the energy consumption, maintenance and labour consumption etc.. For example, energy consumption is a cost property, i.e., a future cost/negative benefit element of a breakdown structure and consumed kWh is its cost *driver*. The driver must be multiplied by its price or monetary value factor. [31] Drivers exist not only for costs but also for benefits (e.g., sold products), risks (e.g., smoked cigarettes per day) and chances.

The *benefit properties* are valuable and precious for customers. Investors are often ready to pay more for them since they increase customers’ subjective benefits by satisfying their needs. Examples of benefit properties are aesthetics, service/comfort, etc..

Safety is both a cost property and a benefit property. Increased safety means fewer damages due to events of damage and, consequently, fewer future costs/negative benefits. Simultaneously, increased safety makes the product more attractive for customers because it satisfies their need for safety. The same applies when it comes to environmental responsibility. A more environmentally-responsible product causes fewer external costs on the one hand while, on the other hand, attracting some customers who have the need to be environmentally.

Future costs usually depend on the output, the level of employment/productivity, and the period of use. Unfortunately, manufacturers do not know how much and how long an investor intends to use their product. However, it is still easier to estimate the value of a cost property because they are multiplied by subjective benefit factors that are usually equal to one. The benefit factors for external costs could be greater than or less than one. The benefit factors for the benefit properties are mostly unknown and more difficult to estimate because every single investor defines them subjectively.

Consequently, the best strategy for manufacturers is to know the exact benefit matrixes of investors in order to satisfy all customers’ needs in the sense of “manufacturing on demand”. To this end, manufacturers should cooperate intensively with their customers or conduct more market research in order to estimate their customers’ benefit factors.

Manufacturers know for certain that lower prices will decrease the initial costs of investors. They do not know exactly how much the improved cost and benefit properties will increase the benefits of the investors. Moreover, manufacturers are less uncertain about cost properties than they are about positive benefit properties. Thus manufacturers should first focus on re-

ducing prices and then on improving cost properties. Additionally, manufacturers should design their products for different classes of customers that use similar benefit factors for the benefit properties.

Of course, prices depend on the cost and benefit properties. For example, an economical engine usually has a higher price. A more comfortable car is also more expensive. Additionally, benefit properties often influence cost properties. For instance, buildings could have higher future costs for energy and maintenance because of more comfort and aesthetics.

Whether a car with an economical engine is the best investment or not depends on the planned consumption of the cost drivers during the entire period of use. Only the system operator could estimate his consumption of the cost drivers because it depends on the demand of his final customers. The demand of his final customers depends due to the competition on the benefit properties and on the prices of his products because rational customers choose mostly products with the optimal profit/profitability.

9.4 Trust, cooperation and contract problems

One of the challenges currently faced by HLCO is poor cooperation between manufacturers and investors or system operators due to a low level of trust. As the result of this *trust and cooperation problem*, manufacturers often lack the required HLCO input data and cannot design optimized products that perfectly satisfy all investors' needs.

The contract problem is the logical consequence of the trust and cooperation problem. The *contract problem* means that investors ask manufacturers for contractual HLCO guarantees. Without them, there is an additional risk for investors that manufacturers could manipulate HLCO calculations in their favour so that the results are suboptimal and the promised HLCO targets cannot be achieved. Of course, manufacturers do not want to give any HLCO guarantees because the actual future outcomes of investments could significantly deviate from the originally planned ones even if the HLCO calculations were not manipulated. [30, 86]

One cause of these significant deviations could be the probabilistic nature of outcomes of investments (e.g., due to economic trends). These probabilistic deviations are part of the investors' business risk. Manufacturers are not responsible for them and must not accept this liability.

Another cause of the significant deviations could be abuse of HLCO guarantees by investors or system operators. They could misuse the system because they know that manufacturers are liable for all detrimental consequences. For instance, they could constantly operate vehicles in first gear or neglect maintenance in order to save money. Therefore, manufacturers refuse to accept liability for these deviations without fair compensation for this transfer of risk.

Indeed, it would be easy to manipulate any HLCO analysis. However, manufacturers cannot give any guarantees for their HLCO calculations. Therefore, the author recommends that investors carry out the HLCO analysis themselves or entrust this work to external planners, but not the manufacturers. Only in cases of “self-made” calculations can investors rely on the analysis results, because they or trustworthy external planners normally do not have any reason to manipulate them. In self-made calculations, investors can control all assumptions made in the HLCO analysis. Thus, HLCO guarantees are no longer required of manufacturers.

Additionally, if investors calculate HLCO themselves, then they do not need to give any sensitive information to manufacturers. They can keep it secret. However, if investors prefer to buy products optimally adapted to their individual needs, they should give the manufacturers all required information about their benefit matrix. Then, according to the concept of *Manufacturing on Demand*, manufacturers can use this HLCO data in cooperation with each other along the supply chain in order to design products optimally adapted to the individual investors' needs.

Reasons for investors not to publish their sensitive HLCO input data could be, for example, competitors or some advantages during price negotiations with manufacturers. In any case, they should compare all advantages and disadvantages of giving their HLCO input data to manufacturers. For invitations to bid, the author recommends always announcing all required HLCO input data.

For their own HLCO calculations, investors need reliable information about the ordinary useful life, the prices for additional guarantees, the benefit properties, the cost properties (depending on the chosen benefit properties), and the prices depending on the chosen cost and benefit properties. All other required input data for the HLCO calculations is estimated only by investors themselves.

Manufacturers must guarantee prices, ordinary useful life, and cost and benefit properties in the contracts. This is usually done anyway in normal, classical contracts. Additionally, guarantees are required for a longer period of use of the investment object. These additional guarantees should be negotiated and charged extra depending on the age of the investment object, the level of investors' deductibles, and eventually on the maintenance program, because the guarantees are insurance for the properties of the investment object. This transfer of risk is an additional service for investors and must be paid for by them.

The guarantees should be very flexible and give every investor the opportunity to adapt individually the insured period and the level of his deductible to his own risk acceptance. The investor should pay the guarantees annually. Annual payments are better than a summed up one-off payment made together with the initial costs because guarantees are future costs but not initial costs. Besides, if investors pay at the beginning for all guarantees and the manufacturer goes bust, then investors lose the guarantees and the insurance premiums. Additionally, investors could prolong or shorten the insured period if they change the moment of the replacement investment or decide to self-insure.

If a guarantee depends on a maintenance program, then to avoid any misuse, maintenance should be carried out by an independent third party and the costs shared between manufacturers and investors. The concrete shares of costs could be negotiated.

Guarantees could be offered not only by manufacturers but also by insurers. Thanks to competition, the prices of the guarantees are expected to be fair. These extra charges make the failure risks transparent for the insured period. They represent the estimates of failure risks made by manufacturers or insurers. If manufacturers charge too little for guarantees they will make losses. If manufacturers charge too much, their products will be more expensive and consequently less attractive for investors.

In any case, it is imperative that investors carry out their own HLCO calculations so that these can be used for a fair comparison of alternatives and as controlling instruments. The comparison of alternatives only makes sense if all HLCO calculations are similarly structured. Of

course, only the investors but not the different manufacturers are able to use the similar structure and to allow deviations from it.

For this task, investors require qualified personnel, which causes additional costs. These costs should be allocated to the HLCO of the investment object. They can eventually be reduced by entrusting this work to external specialists. A holistic analysis of this type is highly interdisciplinary. It is in the fringe area between engineering, computer sciences, and economic sciences.

9.5 Separate calculations for stationary and mobile systems

The question: “How does one calculate the HLCO of stationary and mobile (sub-)systems separately?” is particularly important for railway systems because there are many stationary subsystems such as tracks and many mobile ones such as different types of trains. The stationary and mobile subsystems influence each other with regard to their costs, benefits, risks and chances. It is even worse since these subsystems often belong to different private companies (as it is the case in Germany). This problem can be demonstrated using the ETCS as an example. On the first ETCS level, the costs of trains are lower and the costs of tracks are higher than on the second or third levels because on the first level more functions are performed by tracks than by trains.

The solution is to follow the supply chain. In the first step of the supply chain, the track operator should calculate very precisely the HLCO for using different types of tracks with different types of trains. The stationary subsystems can be optimized independently of the mobile ones. Then the track operator can formulate its prices in a table depending on the type of the track and on the type of the train.

To allocate all consequences to the mobile subsystem, the track operator calculates the damage risks associated with different sets/types of trains (e.g., ICE 3). Furthermore, the “exposure time” an agent of this set spends in the system of the track is known. Additionally, the total exposure time of all trains in the track per year and the total damage risks caused by them are known. Thus it is possible to calculate and allocate the fair share of costs and risks to a mobile subsystem.

In the second step of the supply chain, the train operator uses the track prices to optimize its trains. Thus the HLCO of the trains is simultaneously the HLCO of the whole railway system. As mentioned above, decision quality is the highest if one optimizes the total system instead of optimizing its single subsystems independently of one another. Therefore, it is advisable for track and train operators to cooperate with one another and optimize the total railway system together.

10 European Train Control System (ETCS)

This chapter demonstrates how the newly developed concepts and methods function by applying them to railway systems. The European Train Control System (ETCS) serves as a practical example that is also interesting for international risk management because of its international character and safety relevance. To begin with, the relevant fundamentals of ETCS are described in the first part of the chapter. Afterwards, in the second part, one of the identified ETCS components is analysed by means of the Universal HLCO Approach.

10.1 ETCS as an European standard

At present, fourteen incompatible systems of rules and train control systems obstruct rail traffic across borders and free competition within the European Union. [53, 88] This makes it necessary to change railcars at almost all national frontiers and entails significant delays and additional expenditure. Moreover, locomotives with multiple equipment are a relatively expensive solution.

To standardize train control system for the European Union, the international rail association UIC developed the so-called ERTMS (European Rail Traffic Management System) with the main component called ETCS (European Train Control System). [89]

10.1.1 Objectives, tasks and functions of ETCS for the benefit matrix

The following goals should be achieved through the implementation of ETCS [89, 90, 91]:

- Enabling of step-by-step implementation of the new standardized technologies as a substitute of the national train control systems for the high-speed transportation in the Europe.
- Interoperability of rail networks for European high-speed transportation.
- Shortening or avoiding of technology changes on the national borders in order to reduce the train transportation times.
- Increasing of the line speed and capacity. (This depends on the chosen ETCS level and the existing system.)
- Increasing of safety thanks to the train control system. (This depends on the chosen ETCS level and the existing system.)
- Lower initial costs for ETCS thanks to higher demand of operators and more competition between manufacturers of ETCS components.
- Lowering costs for operation and maintenance of stationary facilities of train control and safety systems.
- Less work for technical services of different rail operators thanks to standardized documentation and European norms.
- Basis for a further standardization of technologies for the international rail traffic.
- Keeping to the local speed limit.
- Keeping to the speed limit of the train.
- The aptitude of the train for all parts of the track and the observance of eventually predetermined operational procedures.
- Preserving train integrity.

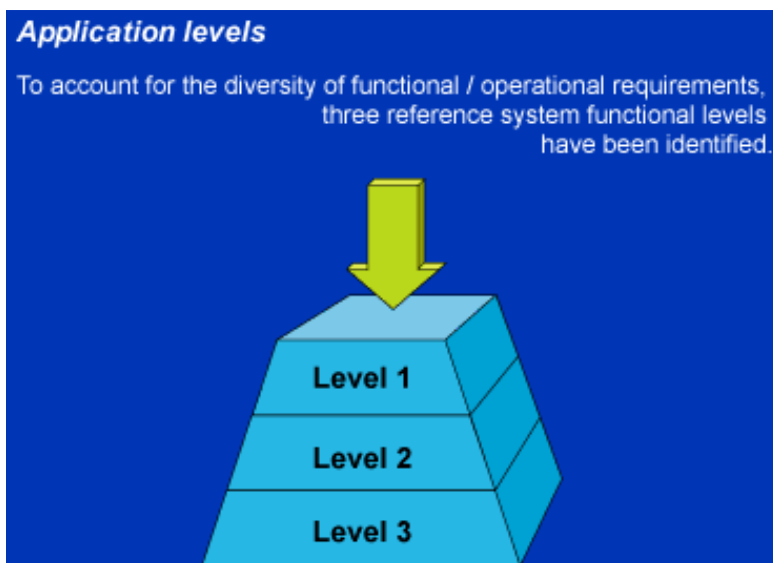
10.1.2 Components of the ETCS for the breakdown structure

The ETCS is modular, i.e., set up of many compatible components that can be combined flexibly with each other according to the project requirements. Thus, the chosen level can be upgraded anytime later. The most important ETCS components are:

- Eurobalise
- LEU (Lineside Electronic Unit)
- Euroloop
- Euroradio GSM-R
- RBC (Radio Block Centre)
- Eurocab with EVC (European Vital Computer) and Juridical Recorder (Black Box) etc.
- MMI (Man Machine Interface)/HMI (Human Machine Interface):
- STM (Specific Transmission Module)

To consider the different equipment variants of the European tracks and different specific requirements in different countries, three ETCS levels were defined as combinations of the ETCS components. [53, 92]

Fig. 10.1: ETCS levels [93]



10.2 ETCS levels as competing investment alternatives, functional and technical description

The rail infrastructure operator can flexibly choose the suitable ETCS level for the level of development of that operator's national train control system. The higher the ETCS level, the less technology on the track and the more in the vehicle. However, only levels 1 and 2 can be realised currently.

The ETCS levels are downwards-compatible. The integrated STMs (Specific Transmission Modules) allow additional usage of the different national train control systems so that their information can be revealed in the ETCS driver's cab. [53]

10.2.1 ETCS level 1

In the level 1 there is still a full locally fixed signalling system with nationally typical signalling. The signal-dependent data is transferred as standardized telegrams by switchable Eurobalises and/or Euroloop to the vehicle. (See Fig. 10.2)

ETCS level 1 is a newly developed, but still classical train control system that entails no advantages over the western European railways. Thus it is virtually only of interest to developing countries which do not have any train control systems at all. [53]

Fig. 10.2: Schematic diagram ETCS level 1 [93]

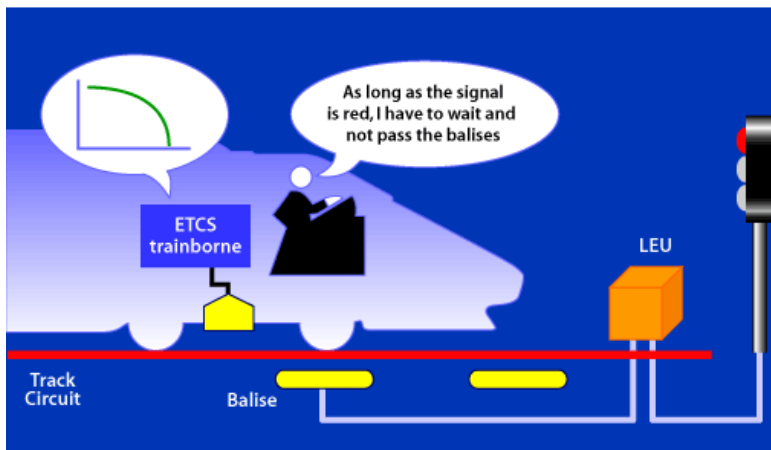
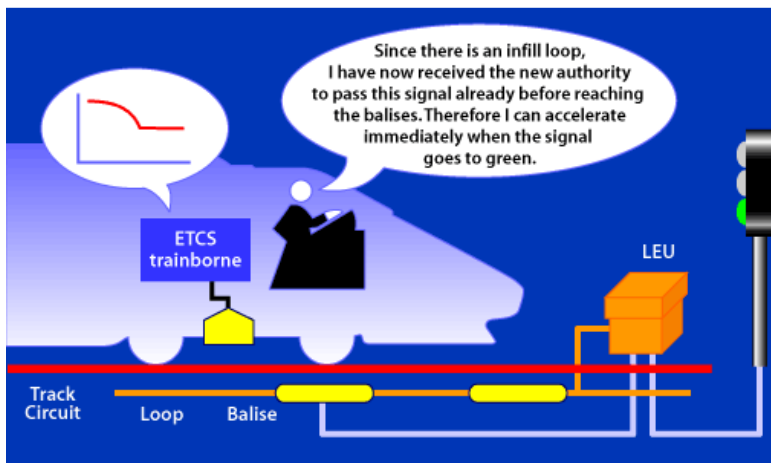


Fig. 10.3: Schematic diagram ETCS level 1 ++ [93]



Components and functions used:

- Information transfer to the train by switchable Eurobalises for finding the position of trains and for continuous safe speed check and braking distance control.
- Track occupation and train integrity control by conventional line-installed track occupation control system.
- Optional Euroloops for transfer of signal upgrading (infill).
- Eurocab for the driver's cab (signal observation is still necessary).
- Train succession control by the classic driving at fixed distance method. [53, 88]

Advantages:

- Standardized ETCS system.
- Calculation and control of braking curves before dangerous points.
- Lower costs than in other levels.
- The control gear can remain unchanged.
- The usage of the Euroloop enables higher capacity of the track like in the second level and the elimination of signals.

Disadvantages:

- Usage of track electric circuits and axle counters. (=> cables and maintenance costs)
- Cables are required for signals and transparent Eurobalises.
- It is possible to start driving while the signal is red.
- Lower capacity of the track because if the signal changes to green the train must drive with the low speed until the next Eurobalise to get this information.
- Safety and availability depends on the control gear used. [94]

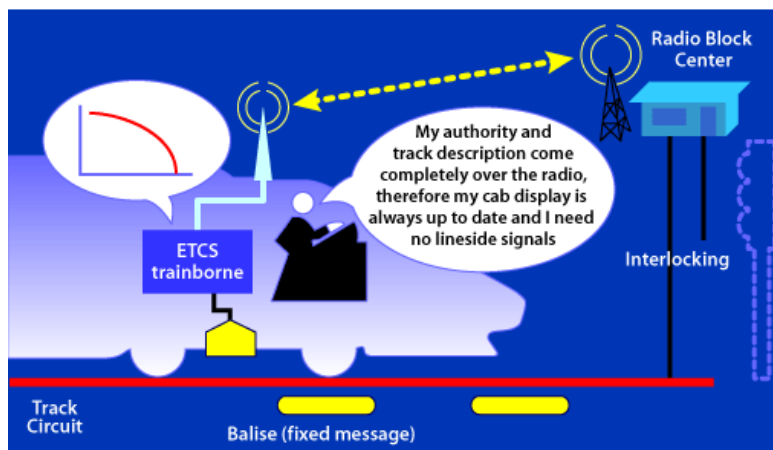
10.2.2 ETCS level 2

In the second level the line-installed signals are almost absent. The trains are controlled by a radio train control. The finding of the position is done by a non-switchable Eurobalise that functions as an electronic milestone. The track occupation control system is realised conventionally (track electric circuits, axle counters). [92] (see Fig. 10.4)

Unlike level 1, level 2 contains a continuous bidirectional information transfer by GSM-R between the train and the track. Thanks to the safe radio and driver's cab-signalling, it is possible to eliminate almost all locally fixed signals. However, it is advisable to retain them as a fallback level at critical points such as switches or for train control for vehicles without ETCS equipment.

The driver of an ETCS train observes only the signals in the driver's cab and ignores any signals that may still exist outside. Furthermore, switchable Eurobalises are no longer required. It is sufficient to use the simpler and cheaper non-switchable Eurobalises. Thanks to the substitution of non-switchable Eurobalises for switchable Eurobalises and of signals with GSM-R, the costs for the installation of cables can be significantly reduced.

The driver gets his orders via radio. The train finds his current position by Eurobalises and calculates his present speed and braking curve. The control gear controls everything. The track occupation and train integrity checking are carried out conventionally using track electric circuits, and axle counters. Therefore, only driving at fixed distance is possible. The radio bloc centre (RBC) controls all vehicles with level 2 cab equipment in his area of responsibility. The RBC transfers orders and information to the trains. When the trains leave the area of responsibility, they register in the next responsible RBC. [89, 92, 95]

Fig. 10.4: Schematic diagram of ETCS level 2 [93]

Components and functions used:

- Bidirectional data communication via GSM-R between the vehicle and the RBC.
- Non-switchable Eurobalises for finding the position.
- Continuous and safe speed check and braking distance control by ATC (Automatic Train Control).
- Track occupation and train integrity checking by conventional line-installed track occupation control system (track electric circuits, axle counters).
- Eurocab for the driver's cab (without signal observation) is combined with classical control gear technology and with fixed block segments for driving at fixed distance.
- Without a fallback level, only trains with ETCS equipment can use the level 2 tracks. [88]

Advantages:

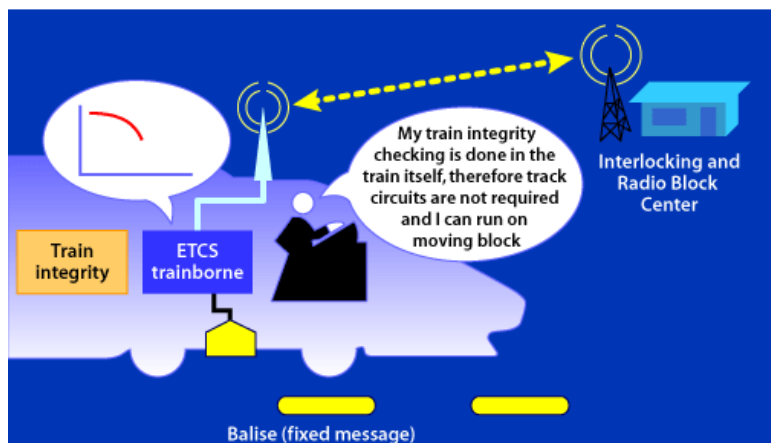
- Standardized ETCS system.
- Calculation and control of braking curves before dangerous points.
- High fallback level.
- No signals.
- No cables are required for signals and transparent Eurobalises.

Disadvantages:

- Usage of track electric circuits, and axle counters (=> cables and maintenance costs)
- GSM-R with a very high availability is required.
- Still no interface of the RBC with relay control gears for signals and points [94]

10.2.3 ETCS level 3

In the third level the trains drive without line-installed signals by means of RBC. The train finds his current position like in level 2 by non-switchable Eurobalises and calculates his present speed and braking curve. There are no conventional line-installed track occupation control system. The train integrity is controlled in the vehicle. Thus, it enables a radio-controlled train sequence control and is more than a pure train control system and allows more than driving at fixed distance. [92] (see Fig. 10.5)

Fig. 10.5: Schematic diagram of ETCS level 3 [93]

Components and functions used:

Similar to the level 2 but with following differences:

- Track occupation control and train integrity checking by position finding and integrity reports of the trains. The trains must have an integrated train integrity control to abolish conventional line-installed track occupation control system (track electric circuits, axle counter). This is now the biggest technical challenge for cargo trains.
- The radio train control allows the train succession control with fixed block segments or with virtual segments or with moving segments.
- Without a fallback level only trains with ETCS equipment can use the level 3 tracks. [88]

Advantages:

- Standardized ETCS system.
- Calculation and control of braking curves before dangerous points.
- High fallback level.
- No signals.
- No cables are required for signals, transparent Eurobalises, track electric circuits, and axle counters.
- No usage of track electric circuits and axle counters.
- Driving at moving block

Disadvantages:

- Still no interface of the RBC with relay control gears for signals and points.
- GSM-R with a very high availability is required.
- Train integrity checking must be aboard trains.
- Level 3 is still not offered by the industry due to lack of a reliable and economical solution for onboard checking of train integrity for the freight rolling stock. [94]

10.3 Train Integrity Checking for freight rolling stock in level 3

ETCS level 3 is the most promising level for the future. Unfortunately, it is still unavailable now for lack of a sufficient technical solution for train integrity checking aboard trains. In passenger trains the train integrity is checked via UIC-data cables. Unfortunately, this solution

is impossible for freight trains because they do not have UIC-data cables. The installation of UIC-data cables in the existing freight wagons or their replacement by newer freight wagons with already installed UIC-data cables would be a very expensive solution. [89]

Currently in Europe, the train integrity of goods trains is controlled by stationary track clearance systems or axle counters which are installed along the lines. In case of technical faults of these stationary systems the local personnel can additionally check the train integrity by means of a special visual signal, which is placed on every last goods wagon. On the old lines without technical train integrity checking the visual signal is regularly controlled by the local personnel.

In current practice, the rail operators incur significant costs and risks for the administration, manipulation and control of the signal. Additional costs are incurred for the stationary infrastructure (track clearance system, axle counters, necessary cables, etc.) as well as for labour for putting up and checking the signal. In case of loosing the signal the train must be stopped and the train integrity checked personally by counting all the goods wagons or by controlling the number of the last one. Afterwards a new signal must be put up. Since the length of goods trains can be 750 meters in Germany and even more in some other European countries, this procedure takes a very long time. Consequently, all following trains must wait. Thus significant expensive delays are caused.

The objective of every rail operator is to automate his system in order to transfer the responsibility from the human personnel to a technical system. The automation increases safety by reducing human errors that are the most frequent cause for incidents. [96]

To enable the ETCS level 3, the author suggests the following new economical solution for this safety and cost relevant system:

The train integrity can be checked by comparing the distance driven by the locomotive at the beginning of the train and by the last goods wagon at the end. The simple principle underlying this technology is the fact that both the first locomotive and the last wagon should always drive almost equal distances. The relatively small deviations occur during positive or negative accelerations due to stretching or compression of the goods train. For the couplings used in Europe the deviation could be maximally ca. 10 m for the total freight train, in USA even smaller. The reaction time to a train separation within 10 m is expected to be few fractions of a second. [97]

These deviations can easily be considered by a simple software (Continue driving if $S_{\text{beginning}} - \Delta S \leq S_{\text{end}}$, otherwise stop due to the train separation) for the European Vital Computer (EVC). Additionally, the reaction time could be significantly reduced by specifying ΔS more precisely dependent on the number of wagons or better couplings in the train. ($\Delta S = \Delta S_{\text{coupling}} * \text{number of couplings in the train}$). The reaction time could be even reduced almost to zero ($\Delta S = 0$) if the devices are synchronized short after the train started to drive so that it is maximally stretched. Eventually the devices could be additionally synchronized by means of Eurobalises that exist in every ETCS level. For this purpose a vehicle antenna will be required for the last goods wagon.

The distance of the first locomotive is regularly measured by a distance meter that is already installed in every locomotive. For measuring the distance of the last goods wagon the author suggests the following three technical methods:

1. A device consisting of a distance meter with a radio transmitter is put up manually by the personnel in the marshalling yard on the last goods wagon. The distance meter permanently measures the distance driven by the last goods wagon in (centi-)metres. Afterwards, this information and the identification number of the device is transmitted as data telegrams via the radio transmitter to the EVC in the locomotive. The device could be put up everywhere in the last goods wagon. However, the author recommends using the last coupling or the wheels. Eventually, EOT (End of Train Telemetry) devices that usually measure the speed and vibrations could be reprogrammed for measuring the distance.

To reduce the costs for the administration and manipulation of the device on the last goods wagon following alternatives are suggested by the author:

2. Less problematic is the use of a goods wagon with a device already installed. This goods wagon can be placed at the end of the goods train automatically in the marshalling yard.
3. Instead of goods wagons, in the second method one can alternatively use new standardized mini-wagons with devices already installed. This could simplify marshalling of goods trains for different destinations of single wagons. Additionally, the distance could be measured very economically by counting wheel rotations. The mini-wagon consists only of four smaller wheels and the device. It has very low additional weight.

Advantages:

1. Since the device is modular it can be installed or uninstalled easily in all three methods.
2. The train operator can choose one or more of the three described technical methods and apply them simultaneously. Thus, the chosen method can be individually adapted to the concrete operational situation.
3. Very short reaction times (fractions of a second) in cases of train separation.
4. Very high safety and availability.
5. It works in all kinds of weather and in tunnels.
6. Relatively low initial costs for the device (simple distance meter + simple radio transmitter for short distances + eventually mini-wagon).

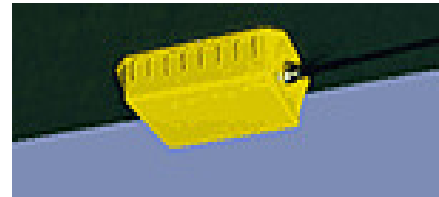
10.4 Eurobalise (Level 1, Level 2, Level 3)

Within the framework of this dissertation only the functionality of the Eurobalise is described and analysed representatively because it is simple and a component of every ETCS level.

The Eurobalise is a stationary system that works according to the transponder principle for the point data transfer. Dependent on the equipment the Eurobalise transfers either signal-independent data (e.g., milestones) or signal-dependent data from the track to the vehicle. The data transfer from the vehicle to a Eurobalise is possible, too. [92]

Fig. 10.6: Eurobalise and its antenna [98]

Eurobalise [99]



Vehicle antenna [99]



In the first ETCS level, switchable Eurobalises (transparent Eurobalises) are installed which are connected up by LEU (Lineside Electronic Unit) with a signal that controls them. In the second and third ETCS levels, non-switchable Eurobalises (fixed data Eurobalises) are used. All Eurobalises know the distance to the neighbouring Eurobalises (in the respective direction).

The Eurobalises are supplied with energy thanks to the induction when an ETCS train passes through. Then they send data telegrams (max. 1024 bits) to the vehicle. The maximal train speed above Eurobalises is 500 km/h. The sent data contains information about the signal status, the position (± 20 cm), the allowed velocity and the distance to the next Eurobalise. The current position of the train is continually calculated in the train until the next Eurobalise by the SDMU (Speed and Distance Measurement Unit) using data from the Doppler radar and velocity sensor. The position is recalibrated by the next Eurobalise. If the next Eurobalise is defect or missing, the train remembers this for the later maintenance. [89, 100]

11 Universal HLCO Approach

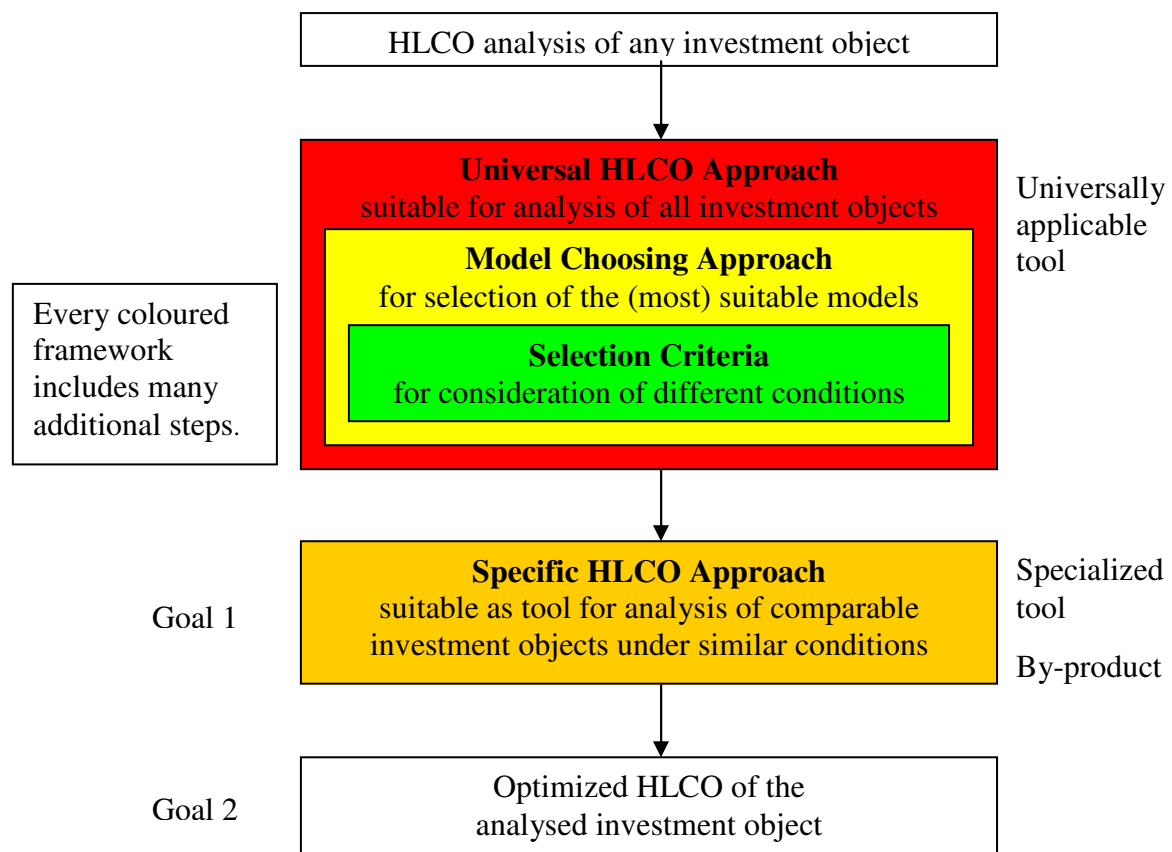
This chapter refines the Universal LCC Approach developed by the author in his master's thesis [30, 53] into a Universal HLCO Approach. Research into the literature on this topic has shown that there are many models and specific approaches, but no general, universal approach to life cycle analysis. On the other hand, Boussabaine and Kirkham also identified a lack of a general economic approach for dealing with risks and risk responses during the life cycle [12].

11.1 Definition of terms in the Universal HLCO Approach

The *Universal HLCO Approach* is a holistic method for optimizing not only all costs, but also all benefits, risks and chances and their dependences associated with the total investment program or parts thereof over the whole life cycle of the investment object or a selected part thereof. The Universal HLCO Approach is used to develop or select the most suitable Specific HLCO Approaches and can be used for HLCO optimization of any investment object.

Since all models and Specific HLCO Approaches have their advantages and disadvantages or preconditions that must be fitted by given conditions, many decision makers do not know how to choose the most suitable models in a concrete situation. The *Model Choosing Approach*, which is an important part of the Universal HLCO Approach, helps decision makers select the (most) suitable models or Specific HLCO Approaches. In the Model Choosing Approach, the *selection criteria* are used to take varying real conditions into consideration.

The *Specific HLCO Approaches* can be used as tools for the optimization of comparable investment objects in situations with similar conditions; thus they reduce and simplify the work associated with HLCO analysis. Specific HLCO Approaches are always by-products of the Universal HLCO Approach and could even be the desired result, the primary goal of this.

Fig. 11.1: Structure chart demonstrating the importance of the Universal HLCO Approach

11.2 Application of Universal HLCO Approach to the Eurobalise

In this subchapter, the functionality of the Universal HLCO Approach is demonstrated by representatively applying it to the non-switchable Eurobalises (fixed data Eurobalises). The approach and all selection forms used in this example are presented in condensed form. This means, for example, that all unnecessary lines and columns can be deleted in order to save space and improve comprehensibility. The complete, blank Universal HLCO Approach is in the Appendix (see Chapter 13.1).

Universal HLCO Approach:

1. Choose one investment object for the further HLCO analysis from Selection Form 1 in Fig. 11.2.

As explained in the previous chapters, the best investment object would be the rail operator’s total investment program. Usually, it is advisable to calculate the HLCO of the three ETCS levels and eventually the remaining HLCO of the existing system in order to compare these competing alternatives. However, for the demonstrating example in this dissertation we choose the non-switchable Eurobalises (fixed data Eurobalises) as the investment object for the HLCO analysis because it is relatively simple to analyse and a component of every ETCS level.

Fig. 11.2: Selection form 1 for investment objects

	Investment objects	Chosen
1.	Total investment program or parts of this	
1.1	Financial investment: e.g., shares or other types of securities etc.	
1.2.	Organizational system(s): e.g., form or structure of enterprise etc.	
1.3.	Technical system(s): e.g., European Train Control System (ETCS) etc.	(x)
1.3.1.	Subsystem(s): e.g., Eurobalise etc.	x

2. Choose the system of goals for the HLCO optimization. The decision maker should define his HLCO goals as exactly as possible. The result of this step is always a hierarchical system of HLCO goals. At least one goal must be selected in every level of the following classification. On some levels several goals can be pursued simultaneously.

In this case we assume the decision maker is a private rail system operator who has to consider his customers’ needs and the interests of the state and society.

Fig. 11.3: Selection form 2 for HLCO goals

	HLCO goals	Chosen
1.	<u>Stakeholders' primal goals:</u> Efficiency = profit/profitability	
1.1.	End users: Efficient satisfaction of their personal needs, the profit/profitability of their budgetary funds spent for that	(x)
1.2.	System operator: The ability to satisfy personal needs of end users, that is the effectiveness of the investment object in regard to its functionalities and the efficiency of the invested resources for that	x
1.3.	Private, profit-oriented shareholders or owners: Efficiency, that is the optimal profit/profitability with maximal commercial benefits	x
1.4.	Public, welfare-oriented shareholders or owners: Efficiency, that is the optimal profit/profitability with maximal public benefits	
1.5.	Manufacturer: Higher product sales thanks to better marketing and higher customer satisfaction.	
1.6.	State or society as total: Sustainable efficiency of the limited societal resources, which means optimal long-term welfare for the entire society. The state and society are represented as well by such stakeholders as state or private social organizations, consumer protection, environmental protection, residents, trade unions, and other different interest groups that pursue their own specific goals.	(x)
1.7.	Lenders, banks: Efficiency, that is profit/profitability of the lent capital	
1.8.	Insurance companies: Efficiency, that is profit/profitability of their insurance business	
2.	<u>Forms of the primal goals:</u>	
2.1.	Maximization <i>or</i> annual stabilization of profit/profitability in the planning period by optimizing all costs and by simultaneously optimizing all benefits (HLCO) <i>or</i>	
2.2.	Maximization <i>or</i> annual stabilization of profit in the planning period by maximizing all benefits for preset/assumed as constant all costs (WLCB) <i>or</i>	
2.3.	Maximization <i>or</i> annual stabilization of profit in the planning period by minimizing all costs for preset/assumed as constant all benefits (WLCC)	x
3.	<u>Secondary goals:</u>	
3.1.	Design goal, that means an active choice from given alternatives by designing an improved one <i>and/or</i>	
3.2.	Selection goal, that means a passive choice from given alternatives by selecting the best one <i>and/or</i>	x
3.3.	Control goal, that means controlling the achievement of desired goals	

3. Define subjective evaluation functions $f_s(b_n)$ and formulate the subjective benefit matrix. The *benefit matrix* serves for solving conflicts between competing subjective benefits (e.g., comfort, aesthetics, etc.). *Evaluation functions* are developed and used by the decision maker for the weight-

ing of stakeholders' subjective benefits in the benefit matrix. Evaluation functions should be formulated monetary. It is recommended to formulate evaluation functions for every subjective benefit and stakeholder (linear or nonlinear with minimal and/or maximal limits). For instance, a wagon must offer the minimal transportation capacity. During the aggregation, all values of subjective benefits b_n must be put in their corresponding evaluation function $f_s(b_n)$. Costs as negative benefits have mostly $f_s(-b_n) = 1 * (-b_n)$. However, sometimes other evaluation functions could be chosen for external costs or damage risks.

The subjective benefit matrix is empty in this example because all subjective benefits such as comfort, aesthetics etc. are irrelevant for the Eurobalise. The evaluation functions for all costs are $f_s(-b_n) = 1 * (-b_n)$.

Fig. 11.4: Form 3 for subjective benefit function

Subjective benefit matrix			b_1 : Comfort	b_2 : Aesthetics	b_3 : etc.	
	Values of benefits b_n					
	Stakeholders	Stakeholders' importance s	$f_s(b_1)$	$f_s(b_2)$	$f_s(b_3)$	Sum
1	Decision maker					$\sum f_1(b_n)$
2	Other planners in the team					$\sum f_2(b_n)$
3	His boss					$\sum f_3(b_n)$
4	External planners/experts					$\sum f_4(b_n)$
5	External safety experts					$\sum f_5(b_n)$
6	Lenders					$\sum f_6(b_n)$
7	Shareholders					$\sum f_7(b_n)$
8	Etc.					$\sum f_8(b_n)$
	Sum	1	$\sum f_s(b_1)$	$\sum f_s(b_2)$	$\sum f_s(b_3)$	$\sum f_s(b_n)$

- Choose the planning period. The length of the planning period should depend on its effects on the total profit/profitability and on subjective preferences of stakeholders. A matrix similar to the subjective benefit matrix should be used to solve conflicts between competing subjective preferences of stakeholders.

In this example we assume that only the decision maker and his boss are significant stakeholders. The importance of all other stakeholders is zero.

Fig. 11.5: Form 4 for planning period

Planning period pl			
	Stakeholders	Stakeholders' importance s	$f_s(pl)$
1	Decision maker	0,4	3
2	Other planners in the team		
3	His boss	0,6	8
4	External planners/experts		
5	External safety experts		
6	Lenders		
7	Shareholders		
8	Etc.		
	Sum	1	$\sum f_s(pl) = 0,6 * 8 + 0,4 * 3 = 6$

5. If some Specific HLCO Approaches are available from similar decision situations, review them for their suitability and eventually adapt them to the given decision situation by means of the Model Choosing Approach or by consulting experts. For the review compare the past/assumed conditions with the real current conditions in the given decision situation. By means of Specific HLCO Approaches the analysis expenditures in similar decision situations can be significantly reduced and the future collection of data improved. However, the quality of analysis results will usually be lower for existing Specific HLCO Approaches than for the individually developed one by means of the Model Choosing Approach.

In our case Specific HLCO Approaches are not available for the Eurobalise.

6. Carry out the Model Choosing Approach for all known potential investment alternatives.
 - 6.1. Classify all existing/known models hierarchically or use existing/known theoretical classifications. The author recommends the following hierarchical classification of models. This classification is limited to the upper levels and should be developed further by adding new model sub-classes and by subdividing them gradually into concrete models on the last level.

Fig. 11.6: Selection form 5 for models

	Models	Chosen
1.	Descriptive and explanatory models	X
1.1.	(Standard) breakdown structures for costs/benefits/risks/chances (e.g., checklists for risk identification)	X
1.1.1	Breakdown structures according to object principle	
1.1.2.	Breakdown structures according to function principle	
1.1.3.	Breakdown structures according to combined principle (object and function principles)	X
1.2.	Net plan oriented methods	
2.	Statistic/stochastic models	X
2.1.	Frequency or probability distribution/function	
2.2.	Mean (m), i.e., statistic arithmetic mean or stochastic expected value	X
2.3.	Geometric mean	
2.4.	Gini-coefficient	
2.5.	Average deviation	
2.6.	Variance	
2.7.	Standard deviation	
2.8.	Skewness	
2.9	Lower and upper partial moments	
2.10.	Failure probability	
2.11.	p-quantile as measure of Value at Risk	
2.12.	Mean risk and average at mean risk	X
2.13.	Mean chance and average at mean chance	X
3.	Prognostic models	X
3.1.	Interviewing experts	X
3.2.	Detailed estimating	X
3.3.	Indicator models	
3.4.	Parametric estimation models	X
3.5.	Etc.	
4.	Temporal aggregation models (dynamic and static)	
4.1.	Net Terminal Value (NTV)	X

4.2.	Net Present Value (NPV)	
4.3.	(Simple or discounted) payback (SPB or DPB)	
4.4.	Net savings (NS)	
4.5.	Net benefits (NB)	
4.6.	Savings to investment ratio (SIR)	
4.7.	Internal rate of return (IRR)	
4.8.	Adjusted internal rate of return (AIRR)	
4.9.	Sinking funds (SF)	
4.10.	Total annual capital charge (TACC)	
5.	Aggregation models	X
5.1.	Aggregation of expected values (with correlation coefficients)	X
5.2.	Aggregation with dependence factors	X
5.3.	Monte Carlo Simulation with correlation coefficients	X
6.	Decision models	
6.1.	Selection decision models	X
6.1.1.	For certainty	
6.1.1.1.	Linear optimization with sensitivity analysis	
6.1.2.	For risks	
6.1.2.1.	Risk neutral decision rule (Bayes' rule, Bernoulli principle: max m)	X
6.1.2.2.	Risk objective decision rules (RRP or ARP)	X
6.1.2.3.	Risk subjective decision rule (max $A_{R,m}$ or max $A_{CH,m}$)	X
6.1.3.	For uncertainty	
6.1.3.1.	Minimax rule	
6.1.3.2.	Maximax rule	
6.1.3.3.	Hurwicz rule	
6.1.3.4.	Laplace rule (max m)	
6.1.3.5.	Savage-Niehans rule	
6.1.3.6.	Uncertainty objective rule (RRP or ARP)	
6.1.3.7.	Uncertainty subjective rule (max $A_{R,m}$ or max $A_{CH,m}$)	
4.2.	Design decision models	X
6.2.1.	Reference models	X

6.2.2.	Mathematical optimization rules	x
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6.2.Pre-select in the hierarchical classification of models the practically relevant models for the following selection forms and exclude too theoretical ones in order to reduce the analysis expenditures and to improve the overview. Since there are too many concrete models for every model subclass it is recommended to reduce if possible their amount to few models reasonable for the analysed investment object. Sometimes such concrete models are developed individually for particular groups of investment objects and must be eventually adapted for concrete decision situations. Such a preliminary selection of models could save a lot of analysis expenditures without endangering the quality of analysis results. The chosen models in the above classification are recommended by the author as practically relevant.

6.3.Select suitable model classes by means of the selection form 6 in Fig. 11.7. The only selection criterion for model classes is the chosen secondary goal.

In this example we analyse only one alternative. Thus, we don't need selection decision models to choose the best alternative from the set of available ones. We just need to know the WLCC of the Eurobalise in order to decide whether we want to purchase it or not.

Fig. 11.7: Selection form 6 for selection of suitable model classes

Model classes	Suitable for following secondary goal(s)	Chosen secondary goal	Possible model classes	Chosen model classes
1. Descriptive/Explanatory models	Design, Selection, Control	Selection	x	x
2. Statistic/Stochastic and Prognostic models	Design, Selection, Control	Selection	x	x
3. Aggregation models	Design, Selection, Control	Selection	x	x
4. Selection decision models	Design, Selection	Selection	x	x
5. Design decision models	Design			

6.4.Select suitable model subclasses for the chosen model classes.

6.4.1. Fill in the selection forms 9-13, in the first columns (called “Model subclasses”) all pre-selected model subclasses for every chosen model class. All irrelevant model subclasses are excluded. For example, if the decision maker has no reference models, he excludes them from the selection form.

6.4.2. Classify all possible selection criteria or use the known/existing classifications. An additional advantage would be if we could specify the selection criteria (for the pre-selected models) more exactly. Thus, we can simplify and improve the further selection of models. For example we can subdivide the model related and project related data into concrete types of data for the respective models. Also the data banks could be structured better thanks to such specified data. The following selection criteria were identified by the author as possible:

Fig. 11.8: Selection form 7 for selection criteria

	Selection criteria	Chosen
1.	Costs of required resources (work as restrictions)	
1.1.	Monetary budget	
1.2.	Time	1
1.3.	Data	
1.3.1.	Type of data	
1.3.1.1.	Historical, <u>model related data</u>	2
1.3.1.1.1.	What data exactly	
1.3.1.2.	Current, <u>project related data</u>	3
1.3.1.2.1.	What data exactly	
1.3.2.	Quantity of data	
1.3.3.	Quality of data	
1.4.	Data processing	
1.4.1.	<u>Computing capacities</u>	4
1.4.2.	Software and capable software users who can program	
1.4.3.	Well-kept data banks	
1.4.4.	Information and communication infrastructure	
1.5.	Experts/labour	
1.5.1.	Intelligence (= computing capacities and capable software users)	
1.5.2.	Theoretical knowledge (= software)	
1.5.3.	Practical experience (= data banks with empirical data)	
1.5.4.	Motivation	
2.	Benefits of the planning are a better quality of decision making	
2.1.	<u>Precision of results: More exact analysis results</u>	5

2.1.1.	Mean risk is lower	
2.1.2.	Mean profitability is higher since better alternatives could be identified and chosen.	
2.2.	Faster decision	
2.3.	Simplifications and (un)realistic <u>assumptions</u>	6
2.3.1.	What assumptions exactly	

- 6.4.3. Choose the relevant selection criteria. The decision maker should assess the relevance of all selection criteria. He should adapt them to his decision situation by excluding irrelevant selection criteria and adding new important ones by subdividing them into a more detailed hierarchical structure.

The six chosen selection criteria are recommended by the author for this example.

- 6.4.4. Group the chosen selection criteria in order to reduce the analysis expenditures and to improve the later overview of the performed analysis steps. For instance, in the above classification, red colour represents costs and restrictions. The red-marked chosen selection criteria must be met mandatory. Otherwise the application of a model subclass or a concrete model is absolutely impossible. Therefore, the red group is first in the selection forms because if the mandatory preconditions for that selection criteria are not met by current conditions, the analysis of all following selection criteria is unnecessary. Green colour represents benefits. These should be higher than costs. The author recommends to rank the selection criteria within the groups in order to reduce the analysis expenditures. Those selection criteria which show empirically a higher exclusion probability for models should be first within their group.
- 6.4.5. Fill in the selection forms 9-13, in the second columns (called “Selection criteria”) the chosen selection criteria in the chosen order.
- 6.4.6. Fill in the selection forms 9-13, in the third columns (called “Preconditions”) the individual preconditions or minimum requirements for application of model subclasses. The preconditions must correspond with the chosen selection criteria. The fuzzy logic allows the decision maker to choose his personal system of assessment for all preconditions, for example in ten categories or from 0 % till 100 % etc.. The author recommends an assessment in five categories: very high; high; middle; low; very low. The preconditions filled in the given selection forms are assessed and recommended by the author. However, the decision maker may change them.
- 6.4.7. Assess current conditions for all chosen selection criteria and fill them in the selection forms 9-13, in the forth columns (called “Current conditions”). The assessment of conditions must correspond with the system of assessment for preconditions. The fifth columns (called “Future conditions”) in the selection forms are reserved for future HLCO analyses by means of the “Specific HLCO Approach” either for the same investment object later, iteratively or for similar investment objects in similar decision situations.

- 6.4.8. Compare in the selection forms 9-13 the assessed conditions with the required corresponding preconditions. Mark the current condition green if it is compatible with its required corresponding precondition. Mark it red if it is not compatible.
- 6.4.9. Mark in the selection forms 9-13, in the sixth columns (called “Possible model subclasses”) all possible model subclasses that could be chosen. Only the satisfaction of red preconditions as minimum requirements and the beneficial profit/profitability of the model are crucial for that. Otherwise, the application of a model subclass or a concrete model is absolutely impossible or inefficient. It is recommended to rank the possible model subclasses. For example, 1 for the best one, 2 for the second best one and so on.
- 6.4.10. Mark in the selection forms, in the seventh columns (called “Chosen model subclasses”) all model subclasses that are chosen for the further HLCO analysis. The decision maker can choose very flexibly many different model subclasses simultaneously for every element of the breakdown structure. It is recommended to rank the chosen model subclasses. For example 1 for the best one, 2 for the second best one and so on. The selection should depend more on the personal assessment by the decision maker and less on the compatibility of current conditions with corresponding preconditions. This means that even if some preconditions are not met, a model subclass may be chosen. The decision maker can favour a model subclass to another one if he expects a higher profit/profitability and the unmet preconditions are less relevant for his concrete situation.
- 6.4.11. Choose one or more calculation principles from the following selection form 8 in Fig. 11.9. If risks and chances are chosen the HLCO analysis is stochastic. Otherwise, it is deterministic.

Fig. 11.9: Selection form 8 for calculation principles

	Calculation principles	Chosen
1.	Costs	x
2.	Benefits	
3.	Risks and Chances	x

- 6.4.12. Select suitable model subclasses for descriptive and explanatory models by means of the selection form 9 in Fig. 11.10 considering the chosen calculation principles.

Fig. 11.10: Selection form 9 for selection of suitable model subclasses for descriptive and explanatory models**Model class: Descriptive and explanatory models**

Model subclasses for Descriptive models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Adaptation and application of existing standard breakdown structures	Time	Low	Middle		1	x
	Model related data	Low	Middle			
	Project related data	Low	Middle			
	Computing capacities	Very low	Low			
	Precision of results	Very high	Middle			
	Assumptions	Low	Low			
Development of new breakdown structures according to combined principle (object and/or function principles)	Time	Middle	Middle		2	
	Model related data	Middle	Middle			
	Project related data	Low	Middle			
	Computing capacities	Very low	Low			
	Precision of results	Very high	Middle			
	Assumptions	Very low	Low			

6.4.13. Realize the chosen breakdown structure. The degree of details of the breakdown structure depends on its effects on the total profit/profitability. (The decision maker could use the same chosen selection criteria to optimize the degree of details.) He should exclude completely or better mark as deactivated such elements of the breakdown structure, whose analysis is expected to be impossible or to have unfavourable profit/profitability. Deactivated elements have the advantage that they are still kept in mind by the decision maker and thus increase the trust into the analysis results. Besides they could be reactivated in later, iterative HLCO optimizations and reduce analysis expenditures for the later reviews of the breakdown structure.

In the appendix the interested reader can find a very detailed breakdown structure for the non-switchable Eurobalise. However, the lowest degree of details is enough to demonstrate our example. Therefore, the standard breakdown structure is reduced to its first level of details. All other elements of the standard breakdown structure are deactivated.

Since in practice many new projects are similar to ones already realized, efforts are made to standardize the breakdown structures. Standard breakdown structures are derived empirically by systematic analysis of comparable finished projects. Standard breakdown structures are not

inflexible universal descriptive models but serve as references of high abstraction degree for construction of adapted project-specific breakdown structures. The following example contains the standard breakdown structure for the non-switchable Eurobalise from the perspective of the system operator. This solution was developed by the author in his master thesis [53]. However, also other standard breakdown structures could exist for the non-switchable Eurobalise. The complete, not filled in standard breakdown structure is in the appendix (see Chapter 13.2).

Fig. 11.11: Standard cost breakdown structure for non-switchable Eurobalise [53, 37]

	Elements of the breakdown structure	Chosen elements	Chosen explanatory models
1.	Research and development (single payment)		
2.	Investment (single payment)	x	
2.1.	Costs of acquisition (single payment)		
2.1.1.	Planning and project management (single payment)		
2.1.2.	Development of project specifications (single payment)		
2.1.3.	Analysing and evaluating of offers (single payment)		
2.1.4.	Quality control (single payment)		
2.1.5.	Costs of ordering (single payment)		
2.1.6.	Costs of documentation (single payment)		
2.2.	Track and signal mark (single payment)		
2.2.1.	Logic (single payment)		
2.2.2.	Breakdowns due to construction and installation work (single payment)		
2.3.	Operational rules and concepts (planning and realisation of ETCS) (single payment)		
2.4.	Costs of adaptation to already used systems (single payment)		
2.5.	Self-financing (single payment)		
2.6.	Financing from outside sources (many repayments for credits in different calculatory periods)		
3.	Operational usage (variable)	x	
3.1.	Operational test (single payment)		
3.2.	Energy: indirect supply of energy during trains pass over by means of induction (variable)		
3.3.	Programming Eurobalises (single payment)		

3.4.	Costs due to unavailability (variable)		
3.4.1.	Costs due to late arrivals (variable)		
3.4.2.	Costs due to accidents (variable)		
4.	Maintenance (fixed)	x	
4.1.	Investment (single payment)		
4.1.1.	Buildings and facilities (single payment)		
4.1.2.	Rents (fixed)		
4.1.3.	Instruments and testing devices (single payment)		
4.1.4.	Planning, controlling and diagnostic systems (single payment)		
4.1.5.	Communication (single payment)		
4.1.6.	Vehicles (single payment)		
4.2.	Personnel (fixed)		
4.2.1.	Wages, salaries, non-wage costs (fixed)		
4.2.2.	Training, education (single payment)		
4.2.3.	Additional support by manufacturers and third firms (fixed)		
4.2.4.	Personnel for the maintenance in the narrow sense (fixed)		
4.2.5.	Personnel for administration and disposition (fixed)		
4.3.	Spare parts (fixed): Usually, Eurobalises are replaced completely if they are defect.		
4.3.1.	Self-made (fixed)		
4.3.2.	Made by external manufacturers (fixed)		
4.4.	Costs of preventive maintenance (fixed)		
4.5.	Costs of corrective maintenance (fixed)		
5.	Modification during a reconstruction e.g., new programming (single payment)		
5.1.	Logic (single payment)		
5.2.	Inspection and approval (single payment)		
5.3.	Integration of new hardware components (single payment)		
6.	Removal (single payment)	x	
6.1.	Shorter period of use than originally planned (single payment)		
6.2.	Dismantling (track and signal mark) (single payment)		

6.3.	Waste disposal (single payment)		
7.	Quality control, project controlling and verification (fixed)		

6.4.14. Select suitable model subclasses for prognostic models by means of the selection form 10 in Fig. 11.12. The selection is carried out for every single element on the last levels of the breakdown structure.

In order to reduce analysis expenditure, it is possible to perform the selection for a group of similar elements together like in our example. For our Eurobalise the results of the selection will be the same for all analysed elements (initial costs, operational usage, maintenance, recycling).

Fig. 11.12: Selection form 10 for selection of suitable model subclasses for prognostic models

Model class: Prognostic models

Element(s) of the breakdown structure:		2. Investment; 3. Operational usage; 4. Maintenance; 6. Removal				
Model subclasses for Prognostic models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Interviewing experts (subjective)	Time	Low	Middle		1	x
	Model related data	Very low	Middle			
	Project related data	Very low	Middle			
	Computing capacities	Very low	Low			
	Precision of results	Middle	Middle			
	Assumptions	Low	Low			
Detailed estimating (partly subjective)	Time	Middle	Middle		2	
	Model related data	Middle	Middle			
	Project related data	Low	Middle			
	Computing capacities	Low	Low			
	Precision of results	Middle	Middle			
	Assumptions	Low	Low			
Application or adaptation of parametric estimation models (objective)	Time	Middle	Middle			
	Model related data	High	Middle			
	Project related data	Low	Middle			

	Computing capacities	Middle	Low		
	Precision of results	High	Middle		
	Assumptions	Low	Low		

6.4.15. Select suitable model subclasses for aggregation models by means of the selection form 11 in Fig. 11.13. The chosen aggregation models should be the same for all analysed investment alternatives.

Fig. 11.13: Selection form 11 for selection of suitable model subclasses for aggregation models

Model class: Aggregation models

Model subclasses for Aggregation models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Aggregation of expected values (with correlation coefficients)	Time	Middle	Middle			
	Model related data	Middle	Middle			
	Project related data	Middle	Middle			
	Computing capacities	Low	Low			
	Precision of results	Low	Middle			
	Assumptions	High	Low			
Aggregation with dependence factors	Time	Middle	Middle		1	x
	Model related data	Middle	Middle			
	Project related data	Middle	Middle			
	Computing capacities	Middle	Low			
	Precision of results	High	Middle			
	Assumptions	Low	Low			
Monte Carlo Simulation (with correlation coefficients)	Time	High	Middle			
	Model related data	High	Middle			
	Project related data	Middle	Middle			
	Computing capacities	Very high	Low			
	Precision of results	High	Middle			
	Assumptions	Low	Low			

6.4.16. Select suitable model subclasses for selection decision models by means of the selection form 12 in Fig. 11.14. The chosen selection decision models must be the same for all analysed investment alternatives.

Fig. 11.14: Selection form 12 for selection of suitable model subclasses for selection decision models

Model class: Selection decision models

Model subclasses for Selection decision models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Risk neutral/objective decision rules	Time	Low	Middle		1	x
	Model related data	Low	Middle			
	Project related data	Low	Middle			
	Computing capacities	Low	Low			
	Precision of results	High	Middle			
	Assumptions	Low	Low			
Risk subjective decision rules	Time	Low	Middle		2	
	Model related data	Low	Middle			
	Project related data	Low	Middle			
	Computing capacities	Low	Low			
	Precision of results	High	Middle			
	Assumptions	Low	Low			

6.4.17. Select suitable model subclasses for design decision models by means of the selection form 13 in Fig. 13.13.

In this example we don't use the selection form 13 because according to the selection form 6 we don't need the design decision models.

6.4.18. Select concrete models by means of selection forms which are similar to the given above selection forms for model subclasses.

For our example we choose the Net Terminal Value as a temporal aggregation model. Unfortunately, we cannot calculate the profitability of our investment object because it is difficult to allocate positive benefits to such a subsystem as the Eurobalise. Therefore, we choose the Ab-

solute Reinvestment Profit as a risk objective decision rule for the calculation of the WLCC. The stochastic/statistic models are correspondingly the mean, the mean risk with the average at mean risk, and the mean chance with the average at mean chance.

- 6.4.19. Summarize and document the results of the Model Choosing Approach as the Specific HLCO Approach. The result of the Model Choosing Approach is always a Specific HLCO Approach that can be applied in a standardized way in all decision situations with similar investment objects and conditions. The results of the selection of model classes and subclasses could finally be summarized for a better overview in a table. Such a table is per definition a Specific HLCO Approach. It is structured similarly to the given above selection forms. Also the breakdown structure and the concrete models selected (and developed) for every element of this breakdown structure should be documented in a joint table.
7. Prepare the already developed concrete models or search, collect and suitably format required model related data for the development of new concrete models. Such model related data are own historical data, historical data of the partners and from the public information sources, expert estimates and forecasts of renowned institutions, new (technological) development trends etc.. For these tasks data banks, the information and communication infrastructure, and data processing capacities are required.
8. Develop new concrete models or use the already developed ones.
9. Search, collect and suitably format required input data for further processing in chosen concrete models. Such input data are own project related data, project related data of the partners and from the public information sources, expert estimates and forecasts of renowned institutions, new (technological) development trends etc.. For these tasks data banks, the information and communication infrastructure, and data processing capacities are required.

According to the ERTMS/ETCS RAMS REQUIREMENT SPECIFICATION “The operational availability of the ERTMS/ETCS, due to all the causes of failure, shall be not less than 0.99973” [101].

ERTMS (UN)AVAILABILITY REQUIREMENTS FOR CONSTITUENTS postulate in the same specification that “The availability (or unavailability) and reliability (or unreliability) requirements [...] will not need to be demonstrated if the specific requirements for the ERTMS Constituents, as listed in the following [...], are fulfilled and demonstrated. This means that the National Railways are free to choose between the availability (or unavailability) requirements [...] and those given in the following [...] when preparing their specific supply contracts for ERTMS/ETCS Applications.

Unavailability:

Non-switchable Eurobalise $< 1\text{E-}7$

Switchable Eurobalise $< 1\text{E-}7$

This option does not apply to Maintainability and Logistic Support Requirements, that remain [...] specified [...]” [101] as following: “The maintenance cost of ERTMS/ETCS shall not exceed the 2 % per year of the System acquisition Cost, for a duration of 30 years of the ERTMS/ETCS Lifecycle.” [101]

10. Process input data in chosen concrete prognostic models.

Unfortunately, the real data are very rare for such a relatively new system as the Eurobalise. Therefore, the author chose “Interviewing experts” as the concrete prognostic model and made his own “expert estimates” and assumptions. Since the primary objective of this example is to demonstrate that the approach works and how it works, in the following all estimated or assumed numbers are chosen very rough in order to keep the example as simple and understandable as possible. Complicated calculations without real data would only cause confusion but not understanding of the approach.

- Investment (initial costs) for one Eurobalise: $m = 500 \text{ €}$; $A_{R,m} = 600 \text{ €}$; $A_{CH,m} = 450 \text{ €}$. For higher investments and amounts of Eurobalises we can eventually define and use a bulk discount function. However, in this simple example we calculate only one Eurobalise.
- Operational usage (future costs): The only future costs due to operational usage of a Eurobalise are the damage risks allocated to them: $m = 100 \text{ € p.a.}$; $A_{R,m} = 300 \text{ € p.a.}$; $A_{CH,m} = 50 \text{ € p.a.}$. The author estimated by means of these three values the damage probability distribution for the unavailability of Eurobalises with the total probability of unavailability $< 1\text{E-}7$.
- Maintenance (future costs): $m = 2 \text{ %}$ per year of the system acquisition cost as postulated in the specification, i.e., 2 % p.a. of the investment: $500 \text{ €} * 2 \text{ %} = 10 \text{ € p.a.}$; $A_{R,m} = 4 \text{ % p.a.}$: $500 \text{ €} * 4 \text{ %} = 20 \text{ € p.a.}$; $A_{CH,m} = 1 \text{ % p.a.}$: $500 \text{ €} * 1 \text{ %} = 5 \text{ € p.a.}$
- Removal (future costs or benefits): The future costs for the recycling at the end of the whole life cycle are estimated as percent of the acquisition cost: $m = 500 \text{ €} * 3 \text{ %} = 15 \text{ €}$; $A_{R,m} = 500 \text{ €} * 5 \text{ %} = 25 \text{ €}$; \therefore ; $A_{CH,m} = 500 \text{ €} * 1 \text{ %} = 5 \text{ €}$.
- The capital costs are considered with the nominal interest rate which represents opportunity costs of the next best investment: $m = 7.5 \text{ % p.a.}$; $A_{R,m} = 12 \text{ % p.a.}$; $A_{CH,m} = 3 \text{ % p.a.}$. The nominal interest rate targeted currently by the German Railways “Deutsche Bahn AG” is 7.5 % p.a. . The deviations could be caused for instance by the inflation.
- The same value as for the planning period is assumed for the period of use and the useful life: 6 years. Usually, such a system is designed for at least 30 years. However, for our calculations we assume only 6 years.

11. Control plausibility of input and output data and model assumptions. If logical inconsistencies are found, repeat some previous steps of the Universal HLCO Approach.
12. If many different prognostic models were used for the same element of the breakdown structure, summarize their processing results using weighted arithmetic mean.
13. Aggregate the processing results of prognostic models in the chosen aggregation models using the subjective benefit matrix. Consider eventually all dependences between the elements of the breakdown structure (e.g., by means of correlation coefficients or by dependence factors).
 - In our example the value of the benefit matrix is zero because the matrix is empty. All evaluation factors for future costs are realistically estimated as equal to 1.
 - Since we don't have statistical data, both the dependence factors are estimated for the worst case as equal to 1.

Fig. 11.15: Aggregation for the mean

Mean m	I(t₀)	b(t₁)	b(t₂)	b(t₃)	b(t₄)	b(t₅)	b(t₆)
Investment in €	-500						
Operational usage in €		-100	-100	-100	-100	-100	-100
Maintenance in €		-10	-10	-10	-10	-10	-10
Removal in €							-15
Cash flows in €	-500	-110	-110	-110	-110	-110	-125
Nominal interest rate in percent	7.5						
WLCC = investment + NTV in €	-500	-647.5	-806.06	-976.52	-1159.76	-1356.74	-1583.49

Fig. 11.16: Aggregation for the average at mean risk $A_{R,m}$

Avarage at mean risk $A_{R,m}$	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$
Investment in €	-600						
Operational usage in €		-300	-300	-300	-300	-300	-300
Maintenance in €		-20	-20	-20	-20	-20	-20
Removal in €							-25
Cash flows in €	-600	-320	-320	-320	-320	-320	-345
Nominal interest rate in percent	12						
WLCC = investment + NTV in €	-600	-992	-1431.04	-1922.76	-2473.5	-3090.32	-3806.15

Fig. 11.17: Aggregation for the average at mean chance $A_{CH,m}$

Average at mean chance $A_{CH,m}$	$I(t_0)$	$b(t_1)$	$b(t_2)$	$b(t_3)$	$b(t_4)$	$b(t_5)$	$b(t_6)$
Investment in €	-450						
Operational usage in €		-50	-50	-50	-50	-50	-50
Maintenance in €		-5	-5	-5	-5	-5	-5
Removal in €							-5
Cash flows in €	-450	-55	-55	-55	-55	-55	-60
Nominal interest rate in percent	3						
WLCC = investment + NTV in €	-450	-518.5	-589.06	-661.73	-736.58	-813.68	-898.09

14. If chosen, process the aggregated results in the selection decision model(s) in order to select passively the best alternative(s).

The chosen selection decision model is the Absolute Reinvestment Profit with the following formula:

If $m_{R,m} = 0$ and $m_{CH,m} = 0$, then $ARP = m$, otherwise

$$\text{If } m > 0, \text{ then } ARP = \frac{m \cdot m_{CH,m}}{m_{R,m}^2} = \frac{m}{m_{R,m}} \cdot \frac{m_{CH,m}}{m_{R,m}}$$

$$\text{If } m < 0, \text{ then } ARP = \frac{m_{R,m}^2}{m \cdot m_{CH,m}} = \frac{m_{R,m}}{m} \cdot \frac{m_{R,m}}{m_{CH,m}}$$

$$m = -1583.49 \text{ €} < 0$$

$$m_{R,m} = m - A_{R,m} = -1583.49 - (-3806.15) = 2222.66 \text{ €} > 0$$

$$m_{CH,m} = A_{CH,m} - m = -898.09 - (-1583.49) = 685.4 \text{ €} > 0$$

$$ARP = \frac{2222.66}{-1583.49} \cdot \frac{2222.66}{685.4} = -1.404 * 3.243 = -4.553$$

The ARP is only a ranking coefficient without a unit of measurement. The ARP of this alternative can be compared with the ARP of other competing alternatives. The alternative with the maximal value is chosen as the best.

15. If chosen, use the design decision models in order to design actively the investment object.

In our example the design selection models are not chosen.

16. Summarize, document and eventually present the final results, particularly for the selected alternative(s).

17. Get final expert recommendations on the basis of the HLCO analysis and make all necessary decisions by formulating all required actions.

18. Carry out all appropriate actions.

19. Document the results for later controls and future HLCO analyses, particularly for the chosen alternative(s).

20. Derive and formulate requirements for future data collection.

21. Repeat regularly, iteratively HLCO analyses for controlling, continuous learning, and improving.

12 Conclusions

This chapter recapitulates all essential new ideas and research results in the dissertation as conclusions. Moreover, the second part of the chapter offers a preview of future developments and research trends in this scientific field.

12.1 Summary of research results

The main objective of this PhD thesis was to optimize allocation of limited resources for risk management by means of Whole Life Cycle Costing. According to the task, the main subject was the relation between safety risk management and WLCC. The formulated problem was to generate a model to evaluate the costs for safety technology versus costs for emergency management from the viewpoint of WLCC.

For this purpose, safety risk management, financial risk management and Whole Life Cycle Costing (WLCC) were combined and refined into a new concept called Holistic Life Cycle Optimization (HLCO). On this basis, a new Universal HLCO Approach that permits flexible and individualized optimization of any investment was developed. One of its important components is the Model Choosing Approach, which systematizes selection of the most suitable models for the HLCO analysis by means of appropriate selection criteria. The Universal HLCO Approach is the perfect tool for evaluating safety technology costs versus emergency management costs from the standpoints of both safety risk management and WLCC. If desired, it optimizes not only all costs but also simultaneously all benefits, uncertainties, risks, chances and dependences of any investment object.

Furthermore, to justify additional investments in risk management measures, a new explanatory model called Marketing Substitution was suggested for quantification and prediction of damages due to subjective risk perception of events of damage. It was applied to safety, security, availability, i.e., to the value of human life and health, environment, cultural heritage, malicious human behaviour such as terrorism etc., and late arrivals.

Additionally, new statistic/stochastic models called Mean Risk and Mean Chance were developed as improved measures of mean negative or positive deviations instead of traditional ones such as absolute deviation, variance, standard deviation, or lower partial moment etc.. Based on them, new improved selection decision models called Relative Reinvestment Profitability and Absolute Reinvestment Profit were developed to summarize any frequency/probability distribution. Selection decision models help to choose the best alternative from the set of available ones.

In order to simultaneously consider all dependences between all random variables, a new aggregation model called Aggregation to Net Terminal Value with Dependence Factors was developed to overcome the weaknesses of correlation and regression analyses. Using it, it is possible to calculate real profitability by means of the net terminal value.

Furthermore, a new computer-aided design decision model called the Simultaneous Design Decision Algorithm was developed to achieve the main objective of the dissertation. It simultaneously optimizes the investment mix, the financial risk reserves, and the credit amount in an accelerated way. Additionally, it can find the optimal replacement alternative and moment if replacement investments are elements in the set of available alternatives. The elements in the optimal investment mix are, among other things, also investments in measures of risk

management. Thus, the optimal investment mix represents the optimal allocation of limited resources for both risk management and WLCC.

Finally, the new concepts and models were demonstrated using railway systems as an example, especially by applying them to the European Train Control System (ETCS). In this context, a new economical and safety-relevant technical principle was developed for onboard train integrity checking.

Altogether, the new theoretical research results are universal and applicable to all investments in practice. Thanks to the synergetic effects in this case, the potential of the developed or improved methodology could be enormous.

12.2 Preview of future research trends and needs

While researching HLCO, the author was able to identify the following potential research trends and needs in this scientific field:

- More attention must be paid to the international nature of risk management. When it comes to rail transportation in particular, it is imperative to deal with the deregulation of the European market.
- Development and improvement of means of risk management.
- Development and improvement of insurance and guarantees for HLCO.
- Development and improvement of descriptive models, i.e., of standard breakdown structures.
- Development and improvement of specifications and requirements for data collection in databases derived from breakdown structures.
- Development and improvement of explanatory and prognostic models for solving the prognosis problem.
- Development and improvement of explanatory and prognostic models for objective environmental damages.
- What discount rate is acceptable from the economic and social points of view?
- Development of design decision models, i.e., reference or mathematical models for economical capacity, economical period of use, maintenance mix, degree of details.
- Automation of the Universal HLCO Approach and the Simultaneous Design Decision Algorithm in user-friendly software.
- Legal regulations for public investments based on HLCO.

13 Appendix

In this chapter the reader can find additional detailed information. This information is collected in the appendix in order to improve the clarity of previous chapters and not to hinder the reading with too many details. (Chapter 13.1 contains new research results.)

13.1 Universal HLCO Approach

1. Choose one investment object for the further HLCO analysis from Selection Form 1 in Fig. 13.1.

Fig. 13.1: Selection form 1 for investment objects

	Investment objects	Chosen
1.	Total investment program or parts of this	x
1.1	Financial investment: e.g., shares or other types of securities etc.	
1.2.	Organizational system(s): e.g., form or structure of enterprise etc.	
1.3.	Technical system(s): e.g., European Train Control System (ETCS) etc.	
1.3.1.	Subsystem(s): e.g., Eurobalise etc.	

2. Choose the system of goals for the HLCO optimization. The decision maker should define his HLCO goals as exactly as possible. The result of this step is always a hierarchical system of HLCO goals. At least one goal must be selected in every level of the following classification of goals. On some levels several goals can be pursued simultaneously.

Fig. 13.2: Selection form 2 for HLCO goals

	HLCO goals	Chosen
1.	<u>Stakeholders' primal goals:</u> Efficiency = profit/profitability	
1.1.	End users: Efficient satisfaction of their personal needs, the profit/profitability of their budgetary funds spent for that	x
1.2.	System operator: The ability to satisfy personal needs of end users, that is the effectiveness of the investment object in regard to its functionalities and the efficiency of the invested resources for that	x
1.3.	Private, profit-oriented shareholders or owners: Efficiency, that is the optimal profit/profitability with maximal commercial benefits	x

1.4.	Public, welfare-oriented shareholders or owners: Efficiency, that is the optimal profit/profitability with maximal public benefits	
1.5.	Manufacturer: Higher product sales thanks to better marketing and higher customer satisfaction.	
1.6.	State or society as total: Sustainable efficiency of the limited societal resources, which means optimal long-term welfare for the entire society. The state and society are represented as well by such stakeholders as state or private social organizations, consumer protection, environmental protection, residents, trade unions, and other different interest groups that pursue their own specific goals.	
1.7.	Lenders, banks: Efficiency, that is profit/profitability of the lent capital	
1.8.	Insurance companies: Efficiency, that is profit/profitability of their insurance business	
2.	<u>Forms of the primal goals:</u>	
2.1.	Maximization <i>or</i> annual stabilization of profit/profitability in the planning period by optimizing all costs and by simultaneously optimizing all benefits (HLCO) <i>or</i>	x
2.2.	Maximization <i>or</i> annual stabilization of profit in the planning period by maximizing all benefits for preset/assumed as constant all costs (WLCB) <i>or</i>	
2.3.	Maximization <i>or</i> annual stabilization of profit in the planning period by minimizing all costs for preset/assumed as constant all benefits (WLCC)	
3.	<u>Secondary goals:</u>	
3.1.	Design goal, that means an active choice from given alternatives by designing an improved one <i>and/or</i>	x
3.2.	Selection goal, that means a passive choice from given alternatives by selecting the best one <i>and/or</i>	
3.3.	Control goal, that means controlling the achievement of desired goals	

3. Define subjective evaluation functions $f_s(b_n)$ and formulate the subjective benefit matrix. The *benefit matrix* serves for solving conflicts between competing subjective benefits (e.g., comfort, aesthetics, etc.). *Evaluation functions* are developed and used by the decision maker for the weighting of stakeholders' subjective benefits in the benefit matrix. Evaluation functions should be formulated monetary. It is recommended to formulate evaluation functions for every subjective benefit and stakeholder (linear or nonlinear with minimal and/or maximal limits). For instance, a wagon must offer the minimal transportation capacity. During the aggregation, all values of subjective benefits b_n must be put in their corresponding evaluation function $f_s(b_n)$. Costs as negative benefits have mostly $f_s(-b_n) = 1 * (-b_n)$. However, sometimes other evaluation functions could be chosen for external costs or damage risks.

Fig. 13.3: Form 3 for subjective benefit function

Subjective benefit matrix			b_1 : Comfort	b_2 : Aesthetics	b_3 : etc.	
	Values of benefits b_n					
	Stakeholders	Stakeholders' importance s	$f_s(b_1)$	$f_s(b_2)$	$f_s(b_3)$	Sum
1	Decision maker	1				$\sum f_1(b_n)$
2	Other planners in the team					$\sum f_2(b_n)$
3	His boss					$\sum f_3(b_n)$
4	External planners/experts					$\sum f_4(b_n)$
5	External safety experts					$\sum f_5(b_n)$
6	Lenders					$\sum f_6(b_n)$
7	Shareholders					$\sum f_7(b_n)$
8	Etc.					$\sum f_8(b_n)$
	Sum	1	$\sum f_s(b_1)$	$\sum f_s(b_2)$	$\sum f_s(b_3)$	$\sum f_s(b_n)$

4. Choose the planning period. The length of the planning period should depend on its effects on the total profit/profitability and on subjective preferences of stakeholders. A matrix similar to the subjective benefit matrix should be used to solve conflicts between competing subjective preferences of stakeholders.

Fig. 13.4: Form 4 for planning period

Planning period pl			
	Stakeholders	Stakeholders' importance s	$f_s(pl)$
1	Decision maker	1	
2	Other planners in the team		
3	His boss		
4	External planners/experts		
5	External safety experts		

6	Lenders		
7	Shareholders		
8	Etc.		
	Sum	1	$\sum f_s(pl)=$

5. If some Specific HLCO Approaches are available from similar decision situations, review them for their suitability and eventually adapt them to the given decision situation by means of the Model Choosing Approach or by consulting experts. For the review compare the past/assumed conditions with the real current conditions in the given decision situation. By means of Specific HLCO Approaches the analysis expenditures in similar decision situations can be significantly reduced and the future collection of data improved. However, the quality of analysis results will usually be lower for existing Specific HLCO Approaches than for the individually developed one by means of the Model Choosing Approach.
 6. Carry out the Model Choosing Approach for all known potential investment alternatives.
- 6.1. Classify all existing/known models hierarchically or use existing/known theoretical classifications. The author recommends the following hierarchical classification of models. This classification is limited to the upper levels and should be developed further by adding new model subclasses and by subdividing them gradually into concrete models on the last level.

Fig. 13.5: Selection form 5 for models

	Models	Chosen
1.	Descriptive and explanatory models	X
1.1.	(Standard) breakdown structures for costs/benefits/risks/chances (e.g., checklists for risk identification)	X
1.1.1	Breakdown structures according to object principle	
1.1.2.	Breakdown structures according to function principle	
1.1.3.	Breakdown structures according to combined principle (object and function principles)	X
1.2.	Net plan oriented methods	
2.	Statistic/stochastic models	X
2.1.	Frequency or probability distribution/function	X
2.2.	Mean (m), i.e., statistic arithmetic mean or stochastic expected value	X
2.3.	Geometric mean	

2.4.	Gini-coefficient	
2.5.	Average deviation	
2.6.	Variance	
2.7.	Standard deviation	
2.8.	Skewness	
2.9	Lower and upper partial moments	
2.10.	Failure probability	X
2.11.	p-quantile as measure of Value at Risk	X
2.12.	Mean risk and average at mean risk	X
2.13.	Mean chance and average at mean chance	X
3.	Prognostic models	X
3.1.	Interviewing experts	X
3.2.	Detailed estimating	X
3.3.	Indicator models	
3.4.	Parametric estimation models	X
3.5.	Etc.	
4.	Temporal aggregation models (dynamic and static)	
4.1.	Net Terminal Value (NTV)	X
4.2.	Net Present Value (NPV)	
4.3.	(Simple or discounted) payback (SPB or DPB)	
4.4.	Net savings (NS)	
4.5.	Net benefits (NB)	
4.6.	Savings to investment ratio (SIR)	
4.7.	Internal rate of return (IRR)	
4.8.	Adjusted internal rate of return (AIRR)	
4.9.	Sinking funds (SF)	
4.10.	Total annual capital charge (TACC)	
5.	Aggregation models	X
5.1.	Aggregation of expected values (with correlation coefficients)	X
5.2.	Aggregation with dependence factors	X
5.3.	Monte Carlo Simulation with correlation coefficients	X

6.	Decision models	
6.1.	Selection decision models	x
6.1.1.	For certainty	
6.1.1.1.	Linear optimization with sensitivity analysis	
6.1.2.	For risks	
6.1.2.1.	Risk neutral decision rule (Bayes' rule, Bernoulli principle: max m)	x
6.1.2.2.	Risk objective decision rules (RRP or ARP)	x
6.1.2.3.	Risk subjective decision rule (max $A_{R,m}$ or max $A_{CH,m}$)	x
6.1.3.	For uncertainty	
6.1.3.1.	Minimax rule	
6.1.3.2.	Maximax rule	
6.1.3.3.	Hurwicz rule	
6.1.3.4.	Laplace rule (max m)	
6.1.3.5.	Savage-Niehans rule	
6.1.3.6.	Uncertainty objective rule (RRP or ARP)	
6.1.3.7.	Uncertainty subjective rule (max $A_{R,m}$ or max $A_{CH,m}$)	
4.2.	Design decision models	x
6.2.1.	Reference models	x
6.2.2.	Mathematical optimization rules	x

6.2.Pre-select in the hierarchical classification of models the practically relevant models for the following selection forms and exclude too theoretical ones in order to reduce the analysis expenditures and to improve the overview. Since there are too many concrete models for every model subclass it is recommended to reduce if possible their amount to few models reasonable for the analysed investment object. Sometimes such concrete models are developed individually for particular groups of investment objects and must be eventually adapted for concrete decision situations. Such a preliminary selection of models could save a lot of analysis expenditures without endangering the quality of analysis results. The chosen models in the above classification are recommended by the author as practically relevant.

6.3.Select suitable model classes by means of the selection form 6 in Fig. 13.6. The only selection criterion for model classes is the chosen secondary goal.

Fig. 13.6: Selection form 6 for selection of suitable model classes

Model classes	Suitable for following secondary goal(s)	Chosen secondary goal	Possible model classes	Chosen model classes
1. Descriptive/Explanatory models	Design, Selection, Control	Selection	x	x
2. Statistic/Stochastic and Prognostic models	Design, Selection, Control	Selection	x	x
3. Aggregation models	Design, Selection, Control	Selection	x	x
4. Selection decision models	Design, Selection	Selection		
5. Design decision models	Design			

6.4. Select suitable model subclasses for the chosen model classes.

6.4.1. Fill in the selection forms 9-13, in the first columns (called “Model subclasses”) all pre-selected model subclasses for every chosen model class. All irrelevant model subclasses are excluded. For example, if the decision maker has no reference models, he excludes them from the selection form.

6.4.2. Classify all possible selection criteria or use the known/existing classifications. An additional advantage would be if we could specify the selection criteria (for the pre-selected models) more exactly. Thus, we can simplify and improve the further selection of models. For example we can subdivide the model related and project related data into concrete types of data for the respective models. Also the data banks could be structured better thanks to such specified data. The following selection criteria were identified by the author as possible:

Fig. 13.7: Selection form 7 for selection criteria

	Selection criteria	Chosen
1.	Costs of required resources (work as restrictions)	
1.1.	Monetary budget	
1.2.	Time	1
1.3.	Data	
1.3.1.	Type of data	
1.3.1.1.	Historical, <u>model related data</u>	2
1.3.1.1.1.	What data exactly	

1.3.1.2.	Current, <u>project related data</u>	3
1.3.1.2.1.	What data exactly	
1.3.2.	Quantity of data	
1.3.3.	Quality of data	
1.4.	Data processing	
1.4.1.	<u>Computing capacities</u>	4
1.4.2.	Software and capable software users who can program	
1.4.3.	Well-kept data banks	
1.4.4.	Information and communication infrastructure	
1.5.	Experts/labour	
1.5.1.	Intelligence (= computing capacities and capable software users)	
1.5.2.	Theoretical knowledge (= software)	
1.5.3.	Practical experience (= data banks with empirical data)	
1.5.4.	Motivation	
2.	Benefits of the planning are a better quality of decision making	
2.1.	<u>Precision of results: More exact analysis results</u>	5
2.1.1.	Mean risk is lower	
2.1.2.	Mean profitability is higher since better alternatives could be identified and chosen.	
2.2.	Faster decision	
2.3.	Simplifications and (un)realistic <u>assumptions</u>	6
2.3.1.	What assumptions exactly	

- 6.4.3. Choose the relevant selection criteria. The decision maker should assess the relevance of all selection criteria. He should adapt them to his decision situation by excluding irrelevant selection criteria and adding new important ones by subdividing them into a more detailed hierarchical structure. The six chosen selection criteria are recommended by the author and used exemplarily in the following selection forms.
- 6.4.4. Group the chosen selection criteria in order to reduce the analysis expenditures and to improve the later overview of the performed analysis steps. For instance, in the above classification, red colour represents costs and restrictions. The red-marked chosen selection criteria must be met mandatory. Otherwise the application of a model subclass or a concrete model is absolutely impossible. Therefore, the red group is first in the selection forms because if the mandatory preconditions for that selection criteria are not met by current conditions, the analysis of all following selection criteria is unnecessary. Green colour represents benefits. These should be higher than costs.

The author recommends ranking the selection criteria within the groups in order to reduce the analysis expenditures. Those selection criteria which show empirically a higher exclusion probability for models should be first within their group.

- 6.4.5. Fill in the selection forms 9-13, in the second columns (called “Selection criteria”) the chosen selection criteria in the chosen order.
- 6.4.6. Fill in the selection forms 9-13, in the third columns (called “Preconditions”) the individual preconditions or minimum requirements for application of model subclasses. The preconditions must correspond with the chosen selection criteria. The fuzzy logic allows the decision maker to choose his personal system of assessment for all preconditions, for example in ten categories or from 0 % till 100 % etc.. The author recommends an assessment in five categories: very high; high; middle; low; very low. The preconditions filled in the given selection forms are assessed and recommended by the author. However, the decision maker may change them.
- 6.4.7. Assess current conditions for all chosen selection criteria and fill them in the selection forms 9-13, in the forth columns (called “Current conditions”). The assessment of conditions must correspond with the system of assessment for preconditions. The fifth columns (called “Future conditions”) in the selection forms are reserved for future HLCO analyses by means of the “Specific HLCO Approach” either for the same investment object later, iteratively or for similar investment objects in similar decision situations.
- 6.4.8. Compare in the selection forms 9-13 the assessed conditions with the required corresponding preconditions. Mark the current condition green if it is compatible with its required corresponding precondition. Mark it red if it is not compatible.
- 6.4.9. Mark in the selection forms 9-13, in the sixth columns (called “Possible model subclasses”) all possible model subclasses that could be chosen. Only the satisfaction of red preconditions as minimum requirements and the beneficial profit/profitability of the model are crucial for that. Otherwise, the application of a model subclass or a concrete model is absolutely impossible or inefficient. It is recommended to rank the possible model subclasses. For example, 1 for the best one, 2 for the second best one and so on.
- 6.4.10. Mark in the selection forms, in the seventh columns (called “Chosen model subclasses”) all model subclasses that are chosen for the further HLCO analysis. The decision maker can choose very flexibly many different model subclasses simultaneously for every element of the breakdown structure. It is recommended to rank the chosen model subclasses. For example 1 for the best one, 2 for the second best one and so on. The selection should depend more on the personal assessment by the decision maker and less on the compatibility of current conditions with corresponding preconditions. This means that even if some preconditions are not met, a model subclass may be chosen. The decision maker can favour a model subclass to another one if he expects a higher profit/profitability and the unmet preconditions are less relevant for his concrete situation.

6.4.11. Choose one or more calculation principles from the following selection form 8 in Fig. 13.8. If risks and chances are chosen the HLCO analysis is stochastic. Otherwise, it is deterministic.

Fig. 13.8: Selection form 8 for calculation principles

	Calculation principles	Chosen
1.	Costs	x
2.	Benefits	x
3.	Risks and Chances	x

6.4.12. Select suitable model subclasses for descriptive and explanatory models by means of the selection form 9 in Fig. 13.9 considering the chosen calculation principles.

Fig. 13.9: Selection form 9 for selection of suitable model subclasses for descriptive and explanatory models

Model class: Descriptive and explanatory models

Model subclasses for Descriptive models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Adaptation and application of existing standard breakdown structures	Time	Low				
	Model related data	Low				
	Project related data	Low				
	Computing capacities	Very low				
	Precision of results	Very high				
	Assumptions	Low				
Development of new breakdown structures according to combined principle (object and/or function principles)	Time	Middle				
	Model related data	Middle				
	Project related data	Low				
	Computing capacities	Very low				
	Precision of results	Very high				
	Assumptions	Very low				

6.4.13. Realize the chosen breakdown structure. The degree of details of the breakdown structure depends on its effects on the total profit/profitability. (The decision maker could use the same chosen selection criteria to optimize the degree of details.) He should exclude completely or better mark as deactivated such elements of the breakdown structure, whose analysis is expected to be impossible or to have unfavourable profit/profitability. Deactivated elements have the advantage that they are still kept in mind by the decision maker and thus increase the trust into the analysis results. Besides they could be reactivated in later, iterative HLCO optimizations and reduce analysis expenditures for the later reviews of the breakdown structure.

6.4.14. Select suitable model subclasses for prognostic models by means of the selection form 10 in Fig. 13.10. The selection is carried out for every single element on the last levels of the breakdown structure.

Fig. 13.10: Selection form 10 for selection of suitable model subclasses for prognostic models

Model class: Prognostic models

Element(s) of the breakdown structure:						
Model subclasses for Prognostic models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Interviewing experts (subjective)	Time	Low				
	Model related data	Very low				
	Project related data	Very low				
	Computing capacities	Very low				
	Precision of results	Middle				
	Assumptions	Low				
Detailed estimating (partly subjective)	Time	Middle				
	Model related data	Middle				
	Project related data	Low				
	Computing capacities	Low				
	Precision of results	Middle				
	Assumptions	Low				
Application or adaptation of parametric estimation models (objective)	Time	Middle				
	Model related data	High				
	Project related data	Low				

	Computing capacities	Middle				
	Precision of results	High				
	Assumptions	Low				

6.4.15. Select suitable model subclasses for aggregation models by means of the selection form 11 in Fig. 13.11. The chosen aggregation models should be the same for all analysed investment alternatives.

Fig. 13.11: Selection form 11 for selection of suitable model subclasses for aggregation models

Model class: Aggregation models

Model subclasses for Aggregation models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Aggregation of expected values (with correlation coefficients)	Time	Middle				
	Model related data	Middle				
	Project related data	Middle				
	Computing capacities	Low				
	Precision of results	Low				
	Assumptions	High				
Aggregation with dependence factors	Time	Middle				
	Model related data	Middle				
	Project related data	Middle				
	Computing capacities	Middle				
	Precision of results	High				
	Assumptions	Low				
Monte Carlo Simulation (with correlation coefficients)	Time	High				
	Model related data	High				
	Project related data	Middle				
	Computing capacities	Very high				
	Precision of results	High				
	Assumptions	Low				

6.4.16. Select suitable model subclasses for selection decision models by means of the selection form 12 in Fig. 13.12. The chosen selection decision models must be the same for all analysed investment alternatives.

Fig. 13.12: Selection form 12 for selection of suitable model subclasses for selection decision models

Model class: Selection decision models

Model subclasses for Selection decision models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Risk neutral/objective decision rules	Time	Very low				
	Model related data	Very low				
	Project related data	Very low				
	Computing capacities	Very low				
	Precision of results	High				
	Assumptions	Middle				
Risk subjective decision rules	Time	Very low				
	Model related data	Low				
	Project related data	Very low				
	Computing capacities	Very low				
	Precision of results	Very high				
	Assumptions	Low				

6.4.17. Select suitable model subclasses for design decision models by means of the selection form 13 in Fig. 13.13.

Fig. 13.13: Selection form 13 for selection of suitable model subclasses for design decision models

Model class: Design decision models

Model subclasses for Design decision models	Selection criteria	Preconditions	Current conditions	Future conditions	Possible model subclasses	Chosen model subclasses
Reference models	Time	Low				

Mathematical optimization rules		Model related data	Very low				
		Project related data	Low				
		Computing capacities	Very low				
		Precision of results	Low				
		Assumptions	High				
		Time	Low				
		Model related data	Middle				
		Project related data	Middle				
		Computing capacities	Very high				
		Precision of results	Very high				
		Assumptions	Middle				

6.4.18. Select concrete models by means of selection forms which are similar to the given above selection forms for model subclasses.

6.4.19. Summarize and document the results of the Model Choosing Approach as the Specific HLCO Approach. The result of the Model Choosing Approach is always a Specific HLCO Approach that can be applied in a standardized way in all decision situations with similar investment objects and conditions. The results of the selection of model classes and subclasses could finally be summarized for a better overview in a table. Such a table is per definition a Specific HLCO Approach. It is structured similarly to the given above selection forms. Also the breakdown structure and the concrete models selected (and developed) for every element of this breakdown structure should be documented in a joint table.

7. Prepare the already developed concrete models or search, collect and suitably format required model related data for the development of new concrete models. Such model related data are own historical data, historical data of the partners and from the public information sources, expert estimates and forecasts of renowned institutions, new (technological) development trends etc.. For these tasks data banks, the information and communication infrastructure, and data processing capacities are required.
8. Develop new concrete models or use the already developed ones.
9. Search, collect and suitably format required input data for further processing in chosen concrete models. Such input data are own project related data, project related data of the partners and from the public information sources, expert estimates and forecasts of renowned institu-

tions, new (technological) development trends etc.. For these tasks data banks, the information and communication infrastructure, and data processing capacities are required.

10. Process input data in chosen concrete prognostic models.
11. Control plausibility of input and output data and model assumptions. If logical inconsistencies are found, repeat some previous steps of the Universal HLCO Approach.
12. If many different prognostic models were used for the same element of the breakdown structure, summarize their processing results using weighted arithmetic mean.
13. Aggregate the processing results of prognostic models in the chosen aggregation models using the subjective benefit matrix. Consider eventually all dependences between the elements of the breakdown structure (e.g., by means of correlation coefficients or by dependence factors).
14. If chosen, process the aggregated results in the selection decision model(s) in order to select passively the best alternative(s).
15. If chosen, use the design decision models in order to design actively the investment object.
16. Summarize, document and eventually present the final results, particularly for the selected alternative(s).
17. Get final expert recommendations on the basis of the HLCO analysis and make all necessary decisions by formulating all required actions.
18. Carry out all appropriate actions.
19. Document the results for later controls and future HLCO analyses, particularly for the chosen alternative(s).
20. Derive and formulate requirements for future data collection.
21. Repeat regularly, iteratively HLCO analyses for controlling, continuous learning, and improving.

8.2 Standard cost breakdown structure for non-switchable Eurobalise

Since in practice many new projects are similar to ones already realized, efforts are made to standardize the breakdown structures. Standard breakdown structures are derived empirically by systematic analysis of comparable finished projects. Standard breakdown structures are not inflexible universal descriptive models but serve as references of high abstraction degree for construction of adapted project-specific breakdown structures. The following example contains the standard breakdown structure for the non-switchable Eurobalise from the perspective of the system operator. This solution was developed by the author in his master thesis [53]. However, also other standard breakdown structures could exist for the non-switchable Eurobalise.

Fig. 13.14: Standard cost breakdown structure for non-switchable Eurobalise [53, 37]

	Elements of the breakdown structure	Chosen elements	Chosen explanatory models
1.	Research and development (single payment)		
2.	Investment (single payment)		
2.1.	Costs of acquisition (single payment)		
2.1.1.	Planning and project management (single payment)		
2.1.2.	Development of project specifications (single payment)		
2.1.3.	Analysing and evaluating of offers (single payment)		
2.1.4.	Quality control (single payment)		
2.1.5.	Costs of ordering (single payment)		
2.1.6.	Costs of documentation (single payment)		
2.2.	Track and signal mark (single payment)		
2.2.1.	Logic (single payment)		
2.2.2.	Breakdowns due to construction and installation work (single payment)		
2.3.	Operational rules and concepts (planning and realisation of ETCS)		
2.4.	Costs of adaptation to already used systems (single payment)		
2.5.	Self-financing (single payment)		
2.6.	Financing from outside sources (many repayments for credits in different calculatory periods)		
3.	Operational usage (variable)		
3.1.	Operational test (single payment)		

3.2.	Energy: indirect supply of energy during trains pass over by means of induction (variable)		
3.3.	Programming Eurobalises (single payment)		
3.4.	Costs due to unavailability (variable)		
3.4.1.	Costs due to late arrivals (variable)		
3.4.2.	Costs due to accidents (variable)		
4.	Maintenance (fixed)		
4.1.	Investment (single payment)		
4.1.1.	Buildings and facilities (single payment)		
4.1.2.	Rents (fixed)		
4.1.3.	Instruments and testing devices (single payment)		
4.1.4.	Planning, controlling and diagnostic systems (single payment)		
4.1.5.	Communication (single payment)		
4.1.6.	Vehicles (single payment)		
4.2.	Personnel (fixed)		
4.2.1.	Wages, salaries, non-wage costs (fixed)		
4.2.2.	Training, education (single payment)		
4.2.3.	Additional support by manufacturers and third firms (fixed)		
4.2.4.	Personnel for the maintenance in the narrow sense (fixed)		
4.2.5.	Personnel for administration and disposition (fixed)		
4.3.	Spare parts (fixed): Usually, Eurobalises are replaced completely if they are defect.		
4.3.1.	Self-made (fixed)		
4.3.2.	Made by external manufacturers (fixed)		
4.4.	Costs of preventive maintenance (fixed)		
4.5.	Costs of corrective maintenance (fixed)		
5.	Modification during a reconstruction e.g., new programming (single payment)		
5.1.	Logic (single payment)		
5.2.	Inspection and approval (single payment)		
5.3.	Integration of new hardware components (single payment)		

6.	Removal (single payment)		
6.1.	Shorter period of use than originally planned (single payment)		
6.2.	Dismantling (track and signal mark) (single payment)		
6.3.	Waste disposal (single payment)		
7.	Quality control, project controlling and verification (fixed)		

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Wir bringen es auf den Punkt.

John L. Fisher
B.A.
Übersetzer
Max-Born-Ring 4c
37077 Göttingen

www.ameritrans.de
Telefon (0551) 306 77 89
Telefax (0551) 205 38 57
fisher@ameritrans.de

Herrn Alexander Jankowski
Am Heerdter Hof 28
40549 Düsseldorf

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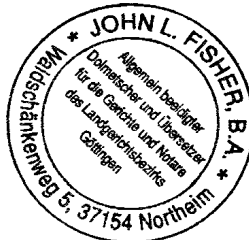
Optimization of Risk Management by Life Cycle Costing
Demonstrated on the European Train Control System

To whom it may concern:

This is to certify that I have edited the aforementioned text and that, to the best of my knowledge and belief, the orthography, grammar, punctuation, numbers, capitalization, style, etc., herein conform to generally accepted practices in modern academic English.

Sincerely,

ameritrans.de



John L. Fisher

Sworn Interpreter and Translator for the Courts and Notaries of the Göttingen Regional Court District

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“Ideals are like stars. We never reach them but, like mariners on the sea, we chart our course by them” [Carl Schurz]